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## 1965

## AUTHOR INDEX OF COLLECTED REPRINTS

1. AHLSTROM, ELBERT H.
Kinds and abundance of fishes in the California Current region based on egg and larval surveys. California Cooperative Oceanic Fisheries Investigations Reports, Volume 10, July 1, 1962-June 30, 1963, p. 31-52, 1965.

2. ALDRICH, DAVID V.
Observations on the ecology and life cycle of Prochristianella penaei Kruse (Cestoda: Trypanorhyncha). The Journal of Parasitology, vol. 51, no. 3, p. 370-376, June 1965.

3. ANDERSON, WILLIAM D., JR., AND ELMER J. GUTHERZ
New Atlantic coast ranges for fishes. Quarterly Journal of the Florida Academy of Sciences, vol. 27(1964), no. 4, p. 299-306, 1965.

4. ANDERSON, WILLIAM W., AND G. ROBERT LUNZ
Southern shrimp...a valuable regional resource. Marine Resources of the Atlantic Coast, Leaflet No. 4, 6 p., October 1965.

5. APPLEGATE, VERNON C., AND M.L.H. THOMAS
Sex ratios and sexual dimorphism among recently transformed sea lampreys, Petromyzon marinus Linnaeus. Journal of the Fisheries Research Board of Canada, vol. 22, no. 3, p. 695-711, 1965.

6. ARON, W., E.H. AHLSTROM, B. MCK. BARY, A.W.H. BÉ, AND W.D. CLARKE
Towing characteristics of plankton sampling gear. Limnology and Oceanography, vol. 10, no. 3, p. 333-340, July 1965.

7. AUSTIN, THOMAS S.
Atlantic Ocean. In Daniel N. Paledes (Editor), McGraw-Hill Yearbook of Science and Technology, McGraw-Hill Book Company, Inc., p. 113-116, 1965.

8. BAKER, EMMETT B., AND ARTHUR S. MERRILL
An observation of Laevicardium mortoni actually swimming. Nautilus, vol. 78, no. 3, p. 104, 1965.

9. BEETON, ALFRED M.

Eutrophication of the St. Lawrence Great Lakes. Limnology and Oceanography, vol. 10, no. 2, p. 240-254, April 1965.

10. ________________, J.F. CARR, AND J.K. HILTUNEN

Sampling efficiencies of three kinds of dredges in southern Lake Michigan. (Abstract) Great Lakes Research Division, The University of Michigan, Publication No. 13, p. 209, 1965.

11. BERRY, FREDERICK H.

The spotted jack crevalle, Caranx melampygus Cuvier, in the eastern Pacific. California Fish and Game, vol. 51, no. 1, p. 28-36, 1965.

12. BILLY, THOMAS J., STACY L. DANIELS, LLOYD L. KEMPE, AND ALFRED M. BEETON

Field application of methods for recovery of the selective lampricide, 3-trifluoromethyl-4-nitrophenol. Great Lakes Research Division, The University of Michigan, Publication No. 13, p. 17-24, 1965.

13. BONNER, RUPERT R., JR.

Observation on tag loss and comparative mortality in striped bass. Chesapeake Science, vol. 6, no. 3, p. 197-198, September 1965.

14. BOSS, KENNETH J.

A new mollusk (Bivalvia, Erycinidae) commensal on the stomatopod crustacean Lysiosquilla. American Museum Novitates, No. 2215, 11 p., March 1965.

15. ________________

Note on Lima (Acesta) angolensis. Nautilus, vol. 79, no. 2, p. 54-58, October 1965.

16. ________________

Catalogue of the family Pandoridae (Mollusca: Bivalvia). Occasional Papers on Mollusks, vol. 2, no. 33, p. 413-424, November 1965.

17. ________________

Symbiotic erycinacean bivalves. Malacologia, vol. 3, no. 2, p. 183-195, 1965.

18. ________________

Convergence of an acentric sculptural trait in the Tellinacea. (Abstract) Annual Reports for 1965 of The American Malacological Union, p. 5-6, 1965.

19. BOSS, KENNETH J., AND ARTHUR S. MERRILL
The family Pandoridae in the western Atlantic. Johnsonia, vol. 4, no. 44, p. 181-215, February 1965.

20. ————————
Degree of host specificity in two species of *Odostomia* (Pyramidellidae: Gastropoda). Proceedings of the Malacological Society of London, vol. 36, part 6, p. 349-355, December 1965.

21. ————————
Benthic ecology and faunal change in the estuary of the Patuxent River. (Abstract) Annual Reports for 1965 of The American Malacological Union, p. 17, 1965.

22. BROENKOW, WILLIAM W.
The distribution of nutrients in the Costa Rica Dome in the eastern tropical Pacific Ocean. Limnology and Oceanography, vol. 10, no. 1, p. 40-52, January 1965.

23. BROWN, BRADFORD E.
Meristic counts of striped bass from Alabama. Transactions of the American Fisheries Society, vol. 94, no. 3, p. 278-279, July 1965.

24. BROWN, EDWARD H., JR., AND CLARENCE F. CLARK
Length-weight relationship of northern pike, *Esox lucius*, from East Harbor, Ohio. Transactions of the American Fisheries Society, vol. 94, no. 4, p. 404-405, October 1965.

25. BROWN, ROBERT P.
Delineation of the layer of maximum salinity in tropical and subtropical oceans by means of bathythermograph traces. Limnology and Oceanography, vol. 10, no. 1, p 157-160, January 1965.

26. BUTLER, PHILIP A.
Reaction of some estuarine mollusks to environmental factors. Biological Problems in Water Pollution, Third Seminar--1962, U.S. Department of Health, Education, and Welfare, Public Health Service Publication No. 999-WP-25, p. 92-104, June 1965.

27. CARR, JOHN F., VERNON C. APPLEGATE, AND MYRL KELLER
A recent occurrence of thermal stratification and low dissolved oxygen in western Lake Erie. The Ohio Journal of Science, vol. 65, no. 6, p. 319-327, November 1965.

28. CARR, JOHN F., AND JARL K. HILTUNEN
Changes in the bottom fauna of western Lake Erie from 1930 to 1961. Limnology and Oceanography, vol. 10, no. 4, p. 551-569, October 1965.

29. CHEEK, RANDALL P.
Pugheadedness in an American shad. Transactions of the American Fisheries Society, vol. 94, no. 1, p. 97-98, January 1965.

30. CLUTTER, ROBERT I.
Self-closing device for sampling plankton near the sea bottom. Limnology and Oceanography, vol. 10, no. 2, p. 293-296, April 1965.

31. COLLETTE, BRUCE B.
Hemiramphidae (Pisces, Synentognathi) from tropical West Africa. Atlantide Report No. 8, p. 217-235, May 1965.

32. ______________
Systematic significance of breeding tubercles in fishes of the family Percidae. Proceedings of the United States National Museum, Smithsonian Institution, vol. 117, no. 3518, p. 567-614, 1965.

33. ______________, AND FREDERICK H. BERRY
Recent studies on the needlefishes (Belonidae): an evaluation. Copeia, no. 3, p. 386-392, September 1965.

34. COLTON, JOHN B., JR.
The distribution and behaviour of pelagic and early demersal stages of haddock in relation to sampling techniques. International Commission for the Northwest Atlantic Fisheries, Special Publication No. 6, p. 317-333, 1965.

35. COOK, HARRY L., AND M. ALICE MURPHY
Early developmental stages of the rock shrimp, Sicyonia brevirostris Stimpson, reared in the laboratory. Tulane Studies in Zoology, vol. 12, no. 4, p. 109-127, October 1965.

36. COOPER, RICHARD ARTHUR
An unusually large menhaden, Brevoortia tyrannus (Latrobe), from Rhode Island. Transactions of the American Fisheries Society, vol. 94, no. 4, p. 412, October 1965.

37. CROKER, ROBERT A., AND ALFRED J. WILSON
Kinetics and effects of DDT in a tidal marsh ditch. Transactions of the American Fisheries Society, vol. 94, no. 2, p. 152-159, April 1965.

38. DANIELS, STACY L., LLOYD L. KEMPE, THOMAS J. BILLY, AND ALFRED M. BEETON
Detection and measurement of organic lampricide residues. Great Lakes Fishery Commission, Technical Report No. 9, 18 p., 1965.

39. DAVIS, JAMES R., AND PAUL R. NICHOLS
Shad on the move: Cape Fear River. Wildlife in North Carolina, vol. 29, no. 4, p. 16-19, April 1965.

40. DIENER, RICHARD A.
The occurrence of tadpoles of the green treefrog, *Hyla cinerea cinerea* (Schneider), in Trinity Bay, Texas. British Journal of Herpetology, vol. 3, no. 8, p. 198-199, 1965.

41. ______________
Texas estuaries and water resource development projects. Proceedings of the Ninth Annual Conference, November 23-24, 1964, Texas A & M University, p. 25-31, 1965.

42. DRAGOVICH, ALEXANDER, JOHN A. KELLY, JUN., AND ROBERT D. KELLY
Red water bloom of a dinoflagellate in Hillsborough Bay, Florida. Nature, vol. 207, no. 5002, p. 1209-1210, September 1965.

43. DRYER, WILLIAM R., LEO F. ERKKILA, AND CLIFFORD L. TETZLOFF
Food of lake trout in Lake Superior. Transactions of the American Fisheries Society, vol. 94, no. 2, p. 169-176, April 1965.

44. DUKE, THOMAS W.
Biogeochemical cycling of radionuclides in the estuarine environment. Proceedings of the Seventeenth Annual Conference, Southeastern Association of Game and Fish Commissioners, Biloxi, Mississippi, September 29-October 2, 1963, p. 315-323, 1965.

45. ______________, JAMES N. WILLIS, AND THOMAS J. PRICE
Cycling of zinc in experimental marine environments. (Abstract) The Association of Southeastern Biologists Bulletin, vol. 12, no. 2, p. 45, April 1965.

46. EDWARDS, R.L.
Relation of temperature to fish abundance and distribution in the southern New England area. International Commission for the Northwest Atlantic Fisheries, Special Publication No. 6, p. 95-110, 1965.

47. EMERY, K.O., ARTHUR S. MERRILL, AND JAMES V.A. TRUMBULL
Geology and biology of the sea floor as deduced from simultaneous photographs and samples. Limnology and Oceanography, vol. 10, no. 1, p. 1-21, January 1965.

48. EMERY, K.O., R.L. WIGLEY, AND MEYER RUBIN
A submerged peat deposit off the Atlantic coast of the United States. Limnology and Oceanography, supplement to vol. 10, p. R97-R102, November 1965.

49. ENGEL, CELESTE G., AND THOMAS E. CHASE
Composition of basalts dredged from seamounts off the west coast of Central America. United States Geological Survey Professional Paper 525-C, p. C161-C163, 1965.

50. ENGEL, DAVID W., JOSEPH W. ANGELOVIC, AND EDNA M. DAVIS
Some effects of an acute dose of $\mathrm{Co}^{60}$ gamma radiation on the blood of the pinfish, *Lagodon rhomboides*. (Abstract) Radiation Research, vol. 25, no. 1, p. 186, May 1965.

51. ESCHMEYER, PAUL H., AND ARTHUR M. PHILLIPS, JR.
Fat content of the flesh of siscowets and lake trout from Lake Superior. Transactions of the American Fisheries Society, vol. 94, no. 1, p. 62-74, January 1965.

52. FARLEY, C. AUSTIN
Acid-fast staining of haplosporidian spores in relation to oyster pathology. Journal of Invertebrate Pathology, vol. 7, no. 2, p. 144-147, June 1965.

53. ________________
A modification of Noland's stain for permanent smears of protozoan flagella, cilia, and spore filaments. The Journal of Parasitology, vol. 51, no. 5, p. 834, October 1965.

54. ________________
Pathologic responses of the oyster, *Crassostrea virginica* (Gmelin), to infection by the protistan parasite, MSX. (Abstract) Annual Reports for 1965 of The American Malacological Union, p. 23-24, 1965.

55. FAVORITE, F., D. Fisk, AND W.J. INGRAHAM, JR.
First transponding oceanographic buoys in the Pacific. Journal of the Fisheries Research Board of Canada, vol. 22, no. 3, p. 689-694, 1965.

56. FINUCANE, JOHN H.
Threadfin shad in Tampa Bay, Florida. Quarterly Journal of the Florida Academy of Sciences, vol. 28, no. 3, p. 267-270, September 1965.

57. FISCHLER, KENNETH J.
The use of catch-effort, catch-sampling, and tagging data to estimate a population of blue crabs. Transactions of the American Fisheries Society, vol. 94, no. 4, p. 287-310, October 1965.

58. FISCUS, CLIFFORD H.
Pelagic fur seal research in the eastern Pacific. (Abstract) Proceedings of the Fifteenth Alaskan Science Conference, College, Alaska, August 31-September 4, 1964, p. 42, March 1965.

59. FLEMINGER, ABRAHAM, AND ROBERT I. CLUTTER
Avoidance of towed nets by zooplankton. Limnology and Oceanography, vol. 10, no. 1, p. 96-104, January 1965.

60. FORSBERGH, ERIC D., AND WILLIAM W. BROENKOW
Oceanographic observations from the eastern Pacific Ocean collected by the R/V *Shoyo Maru*, October 1963-March 1964. Inter-American Tropical Tuna Commission Bulletin, vol. 10, no. 2, p. 85-237, 1965.

61. FREDIN, R.A.
Some methods for estimating ocean mortality of Pacific salmon and applications. Journal of the Fisheries Research Board of Canada, vol. 22, no. 1, p. 33-51, 1965.

62. FRENCH, ROBERT R.
Dropout rate for high seas gillnets studied by U.S. fisheries biologists. Pacific Fisherman, vol. 63, no. 4, p. 10-11, March 1965.

63. ————————
Visceral adhesions in high-seas salmon. Transactions of the American Fisheries Society, vol. 94, no. 2, p. 177-181, April 1965.

64. FRITZ, RAYMOND L.
Autumn distribution of groundfish species in the Gulf of Maine and adjacent waters, 1955-1961. Serial Atlas of the Marine Environment, American Geographical Society, Folio 10, 26 p., 1965.

65. GRAHAM, JOSEPH J., AND HAROLD C. BOYAR
Ecology of herring larvae in the coastal waters of Maine. International Commission for the Northwest Atlantic Fisheries, Special Publication No. 6, p. 625-634, 1965.

66. GRAHAM, JOSEPH J., AND GEORGE B. VAUGHAN
A new depressor design for high speed samplers. (Abstract) Ocean Science and Ocean Engineering, vol. 2, p. 742, 1965.

67. GROVES, ALAN B., AND ANTHONY J. NOVOTNY
A thermal-marking technique for juvenile salmonids. Transactions of the American Fisheries Society, vol. 94, no. 4, p. 386-389, October 1965.

68. GUTKNECHT, JOHN
Uptake and retention of Cesium 137 and Zinc 65 by seaweeds. Limnology and Oceanography, vol. 10, no. 1, p. 58-66, January 1966.

69. ________________
Ion distribution and transport in the red marine alga, *Gracilaria foliifera*. Biological Bulletin, vol. 129, no. 3, p. 495-509, December 1965.

70. HANKS, ROBERT W.
Effect of metallic aluminum particles on oysters and clams. Chesapeake Science, vol. 6, no. 3, p. 146-149, September 1965.

71. HEARD, WILLIAM R.
Limnetic cottid larvae and their utilization as food by juvenile sockeye salmon. Transactions of the American Fisheries Society, vol. 94, no. 2, p. 191-193, April 1965.

72. HENNEMUTH, R.C.
Homogeneity of age-length frequencies among months and quarters of the year for haddock caught on Georges Bank, 1962. International Commission for the Northwest Atlantic Fisheries, Research Bulletin No. 2, p. 76-77, 1965.

73. HENRY, KENNETH A., EDWIN B. JOSEPH, CHARLES M. BEARDEN, AND JOHN W. REINTJES
Atlantic menhaden...a most abundant fish. Marine Resources of the Atlantic Coast, Leaflet No. 2, 4 p., October 1965.

74. HIDU, HERBERT
Effects of synthetic surfactants on the larvae of clams (*M. mercenaria*) and oysters (*C. virginica*). Journal Water Pollution Control Federation, vol. 37, no. 2, p. 262-270, February 1965.

75. HILTUNEN, JARL K.
Distribution and abundance of the polychaete, Manayunkia speciosa Leidy, in western Lake Erie. The Ohio Journal of Science, vol. 65, no. 4, p. 183-185, July 1965.

76. HODGINS, HAROLD O., GEORGE J. RIDGWAY, AND FRED M. UTTER
Electrophoretic mobility of an immune globulin from rainbow trout serum. Nature, vol. 208, no. 5015, p. 1106-1107, December 1965.

77. HOLLAND, RUTH E.
The distribution and abundance of planktonic diatoms in Lake Superior. Great Lakes Research Division, The University of Michigan, Publication No. 13, p. 96-105, 1965.

78. JENSEN, ALBERT C.
A standard terminology and notation for otolith readers. International Commission for the Northwest Atlantic Fisheries, Research Bulletin No. 2, p. 5-7, 1965.

79. JONES, EVERET C.
The general distribution of species of the calanoid copepod family Candaciidae in the Indian Ocean with new records. (Abstract) Symposium on Crustacea, Marine Biological Association of India, January 12-15, 1965, p. 17-18.

80. ______________
Evidence of isolation between populations of Candacia pachydactyla (Dana) (Copepoda: Calanoida) in the Atlantic and the Indo-Pacific Oceans. (Abstract) Symposium on Crustacea, Marine Biological Association of India, January 12-15, 1965, p. 18.

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81. KATO, SUSUMU
White shark Carcharodon carcharias from the Gulf of California with a list of sharks seen in Mazatlan, Mexico, 1964. Copeia, no. 3, p. 384, September 1965.

82. KELLY, GEORGE F., AND ALLAN M. BARKER
The copepod ectoparasite Sphyrion lumpi (Kroyer) in relation to redfish Sebastes marinus (L.) in the Gulf of Maine. International Commission for the Northwest Atlantic Fisheries, Special Publication No. 6, p. 481-500, 1965.

83. KEYES, MARK C.
Pathology of the northern fur seal. Journal of the American Veterinary Medical Association, vol. 147, no. 10, p. 1090-1095, November 1965.

84. KIRKWOOD, JAMES B., AND ROBERT M. YANCEY
Effects of the March 27 earthquake upon the shellfish resources of Alaska. Proceedings Fifteenth Alaskan Science Conference, College, Alaska, August 31-September 4, 1964, p. 162, March 1965.

85. LASKER, REUBEN
Growth and carbon metabolism of euphausiid crustaceans. (Abstract) American Zoologist, vol. 5, no. 4, p. 706, November 1965.

86. ____________
The physiology of Pacific sardine embryos and larvae. California Cooperative Oceanic Fisheries Investigations Reports, Vol. 10, July 1, 1962-June 30, 1963, p. 96-101, 1965.

87. ____________, AND GAIL H. THEILACKER
Maintenance of euphausiid shrimps in the laboratory. Limnology and Oceanography, vol. 10, no. 2, p. 287-288, April 1965.

88. LEWIS, ROBERT M.
The effect of minimum temperature on the survival of larval Atlantic menhaden, *Brevoortia tyrannus*. Transactions of the American Fisheries Society, vol. 94, no. 4, p. 409-412, October 1965.

89. LINDNER, MILTON J.
Postlarval brown shrimp abundance and fishing success. (Abstract) Proceedings of the Gulf and Caribbean Fisheries Institute, Seventeenth Annual Session, November 1965, p. 19.

90. LOOSANOFF, VICTOR L.
Mariculture...its recent development and its future. Agricultural Engineering, vol. 46, no. 2, p. 73, 93-97, February 1965.

91. ____________
Gonad development and discharge of spawn in oysters of Long Island Sound. Biological Bulletin, vol. 129, no. 3, p. 546-561, December 1965.

92. ____________
Pesticides in sea water and the possibilities of their use in mariculture. Research in Pesticides, Academic Press Inc., New York, 1965, p. 135-145.

93. LOWE, JACK L.
Chronic exposure of blue crabs, Callinectes sapidus, to sublethal concentrations of DDT. Ecology, vol. 46, no. 6, p. 899-900, 1965.

94. LUCICH, GEORGE M., JULIUS ROCKWELL, JR., AND ROBERT E. BERGSTROM
Multiple electrode detector. United States Patent Office, No. 3,223,319, December 14, 1965, 6 p.

95. MCLAIN, ALBERTON L., BERNARD R. SMITH, AND HARRY H. MOORE
Experimental control of sea lampreys with electricity on the south shore of Lake Superior, 1953-60. Great Lakes Fishery Commission, Technical Report No. 10, 48 p., 1965.

96. MANAR, THOMAS A.
Tuna behavior: A growing field for research. Pacific Fisherman, vol. 63, no. 11, p. 9-11, October 1965.

97. MANZER, J.I., T. ISHIDA, A.E. PETERSON, AND M.G. HANAVAN
Salmon of the North Pacific Ocean--Part V. Offshore distribution of salmon. International North Pacific Fisheries Commission, Bulletin No. 15, 452 p., 1965.

98. MARR, JOHN C.
Oceanographic instrumentation and Hawaiian fisheries. Proceedings of the Governor's Conference on Science and Technology, State of Hawaii, January 26-30, 1965, p. 67-72.

99. MARVIN, KENNETH T., AND RAPHAEL R. PROCTOR, JR.
Stabilizing the ammonia-nitrogen content of estuarine and coastal waters by freezing. Limnology and Oceanography, vol. 10, no. 2, p. 288-290, April 1965.

100. MASON, JAMES E.
Salmon of the North Pacific Ocean--Part IX. Coho, chinook and masu salmon in offshore waters. 2. Chinook salmon in offshore waters. International North Pacific Fisheries Commission, Bulletin No. 16, p. 41-73, 1965.

101. MERRILL, ARTHUR S.
The benefits of systematic biological collecting from navigation buoys. The Association of Southeastern Biologists Bulletin, vol. 12, no. 1, p. 3-8, January 1965.

102. MERRILL, ARTHUR S.
The surf clam fishery. (Abstract) Annual Reports for 1965 of The American Malacological Union, p. 4-5, 1965.

103. ________________, K.O. EMERY, AND MEYER RUBIN
Ancient oyster shells on the Atlantic Continental Shelf. Science, vol. 147, no. 3656, p. 398-400, January 1965.

104. ________________, AND RICHARD E. PETIT
Mollusks new to South Carolina. Nautilus, vol. 79, no. 2, p. 58-66, October 1965.

105. MILLER, GEORGE C.
A new species of searobin (Triglidae). Quarterly Journal of the Florida Academy of Sciences, vol. 28, no. 3, p. 259-266, 1965.

106. ________________
Western North American crawfishes (Pacifastacus) in brackish water environments. Research Briefs, Fish Commission of Oregon, vol. 11, no. 1, p. 42-50, June 1965.

107. MIYAHARA, TAKASHI, AND HERBERT H. SHIPPEN
Preliminary report of the effect of varying levels of fishing on eastern Bering Sea king crabs, Paralithodes camtschatica (Tilesius). Conseil Permanent International pour l'Exploration de la Mer, Rapports et Procès-Verbaux, vol. 156, p. 51-58, 1965.

108. MOCK, CORNELIUS R.
Range extension of the sipunculoidean annelid Phascolion strombi (Montagu) in the Gulf of Mexico. The Texas Journal of Science, vol. 17, no. 2, p. 239-240, June 1965.

109. NAKAMURA, EUGENE L.
Food and feeding habits of skipjack tuna (Katsuwonus pelamis) from the Marquesas and Tuamotu Islands. Transactions of the American Fisheries Society, vol. 94, no. 3, p. 236-242, July 1965.

110. ________________, AND JOHN J. MAGNUSON
Coloration of the scombrid fish Euthynnus affinis (Cantor). Copeia, no. 2, p. 234-235, June 1965.

111. OLSEN, O. WILFORD, AND EUGENE T. LYONS
Life cycle of Uncinaria lucasi Stiles, 1901 (Nematoda: Ancylostomatidae) of fur seals, Callorhinus ursinus Linn., on the Pribilof Islands, Alaska. The Journal of Parasitology, vol. 51, no. 5, p. 689-700, October 1965.

112. PARKER, JACK C.
An annotated checklist of the fishes of the Galveston Bay system, Texas. Publications of the Institute of Marine Science, Texas, vol. 10, p. 201-220, June 1965.

113. PATTEN, BENJAMIN G., DUANE T. RODMAN, AND KENNETH D. WALDRON
The Pacific bonito, Sarda chiliensis (Cuvier), in Puget Sound, Washington. California Fish and Game, vol. 51, no. 4, p. 298-299, 1965.

114. PERKINS, FRANK E.
Incubation of fall-spawned eggs of the little skate, Raja erinacea (Mitchill), Copeia, no. 1, p. 114-115, March 1965.

115. PETERSON, RICHARD S.
Drugs for handling fur seals. The Journal of Wildlife Management, vol. 29, no. 4, p. 688-693, October 1965.

116. PRICE, THOMAS J.
Accumulation of radionuclides and the effects of radiation on molluscs. Biological Problems in Water Pollution, Third Seminar--1962, U.S. Department of Health, Education, and Welfare, Public Health Service Publication No. 999-WP-25, p. 202-210, 1965.

117. PYCHA, RICHARD L., WILLIAM R. DRYER, AND GEORGE R. KING
Movements of hatchery-reared lake trout in Lake Superior. Journal of the Fisheries Research Board of Canada, vol. 22, no. 4, p. 999-1024, 1965.

118. RAHRER, JEROLD F.
Age, growth, maturity, and fecundity of "humper" lake trout, Isle Royale, Lake Superior. Transactions of the American Fisheries Society, vol. 94, no. 1, p. 75-83, January 1965.

119. RICE, DALE W.
Offshore southward migration of gray whales off southern California. Journal of Mammalogy, vol. 46, no. 3, p. 504-505, August 1965.

120. ____________
Bryde's whale in the Gulf of Mexico. Norsk Hvalfangst-Tidende, no. 5, p. 114-115, 1965.

121. ____________, KARL W. KENYON, AND DANIEL LLUCH B.
Pinniped populations at Islas Guadalupe, San Benito, and Cedros, Baja California, in 1965. Transactions of the San Diego Society of Natural History, vol. 14, no. 7, p. 73-84, December 1965.

122. RICE, T.R.
Radioisotope techniques in fishery research. Transactions of the Thirtieth North American Wildlife and Natural Resources Conference, March 8-10, 1965, p. 66-76.

123. ________________
The role of plants and animals in the cycling of radionuclides in the marine environment. Health Physics, vol. 11, p. 953-964, 1965.

124. ________________, J.P. BAPTIST, AND T.J. PRICE
Accumulation of mixed fission products by marine organisms. The Proceedings of the Second International Water Pollution Research Conference, Tokyo 1964, p. 263-286, 1965.

125. ROPES, JOHN W., AND ALDEN P. STICKNEY
Reproductive cycle of *Mya arenaria* in New England. Biological Bulletin, vol. 128, no. 2, p. 315-327, April 1965.

126. ROPPEL, ALTON Y., AND STUART P. DAVEY
Evolution of fur seal management on the Pribilof Islands. The Journal of Wildlife Management, vol. 29, no. 3, p. 448-463, July 1965.

127. ROSENFIELD, AARON
Maintenance of oyster tissue *in vitro*. (Abstract) Annual Reports for 1965 of The American Malacological Union, p. 30, 1965.

128. ________________, AND CARL J. SINDERMANN
Starch-gel electrophoresis of oyster serum. (Abstract) Annual Reports for 1965 of The American Malacological Union, p. 8-9, 1965.

129. ROTHSCHILD, BRIAN J.
Some uses of statistics in fishery biology. Proceedings of the Interdisciplinary Conference on Mathematics, Agent of Change in the Biological Sciences, Physical Sciences, Social Sciences, and the Humanities, College of General Studies, University of Hawaii, April 20-21, 1965, p. 179-187.

130. SAUR, J.F.T.
Impressions of the conference. *In* Gifford C. Ewing (Editor), Oceanography from Space, Reference No. 65-10, Woods Hole Oceanographic Institution, p. 175-176, April 1965.

131. SAUR, J.F.T.
Oceanographic observations from manned satellites for fishery research and commercial fishery applications. In Gifford C. Ewing (Editor), Oceanography from Space, Reference No. 65-10, Woods Hole Oceanographic Institution, p. 313-314, April 1965.

132. SAWYER, THOMAS K.
Molting and exsheathment in vitro of third-stage Dirofilaria immitis. The Journal of Parasitology, vol. 51, no. 6, p. 1016-1017, December 1965.

133. ________________, ELLIS F. RUBIN, AND RONALD F. JACKSON
The cephalic hook in microfilariae of Dipetalonema reconditum in the differentiation of canine microfilariae. Proceedings of The Helminthological Society of Washington, vol. 32, no. 1, p. 15-20, January 1965.

134. SCHUMANN, GEORGE O.
Some aspects of behavior in clupeid larvae. California Cooperative Oceanic Fishery Investigations Reports, Volume 10, July 1, 1962-June 30, 1963, p. 71-78, 1965.

135. SETTE, OSCAR E.
Computer preparation of surface sea temperature observations for analysis and charting. Proceedings of the ONR-NSIA Symposium on Automatic Collection, Processing and Analysis of Oceanographic Data, University of California, San Diego, December 11-12, 1964, p. 59-60, October 1965.

136. SHAW, WILLIAM N.
Pond culture of oysters--past, present, and future. Transactions of the Thirtieth North American Wildlife and Natural Resources Conference, March 8-10, 1965, p. 114-120.

137. ________________
Seasonal setting patterns of five species of bivalves in the Tred Avon River, Maryland. Chesapeake Science, vol. 6, no. 1, p. 33-37, March 1965.

138. SHERMAN, KENNETH
Seasonal and areal distribution of Gulf of Maine coastal zooplankton, 1963. International Commission for the Northwest Atlantic Fisheries, Special Publication No. 6, p. 611-623, 1965.

139. ________________
The use of hard parts of fishes for growth determination. Research Problems in Biology, Series 4, p. 160-164, 1965.

140. SHERMAN, KENNETH, AND EVERETT G. SCHANER
Paracineta sp., an epizoic suctorian found on Gulf of Maine Copepoda. The Journal of Protozoology, vol. 12, no. 4, p. 618-625, 1965.

141. SHOMURA, RICHARD S., AND THOMAS S. HIDA
Stomach contents of a dolphin caught in Hawaiian waters. Journal of Mammalogy, vol. 46, no. 3, p. 500-501, August 1965.

142. SINDERMANN, CARL J.
Effects of environment on several diseases of herring from the western North Atlantic. International Commission for the Northwest Atlantic Fisheries, Special Publication No. 6, p. 603-610, 1965.

143. SKUD, BERNARD E.
Federal fisheries research expanding in Maine. Portland Press Herald, State of Maine Edition, July 3, 1965, 1 p.

144. SPRAGUE, LUCIAN M.
Fish immunogenetics research. Science, vol. 148, no. 3674, p. 1252-1254, May 1965.

145. STEARNS, FRANKLIN
Sea-surface temperature anomaly study of records from Atlantic coast stations. Journal of Geophysical Research, vol. 70, no. 2, p. 283-296, January 1965.

146. STRASBURG, DONALD W.
Description of the larva and familial relationships of the fish Snyderidia canina. Copeia, no. 1, p. 20-24, March 1965.

147. ______________
A submarine for research in fisheries and oceanography. Ocean Science and Ocean Engineering, Transactions of the Joint Conference, Marine Technology Society and American Society of Limnology and Oceanography, Washington, D.C., June 1965, p. 568-571, 1965.

148. STUNKARD, HORACE W., AND FRED E. LUX
A microsporidian infection of the digestive tract of the winter flounder, Pseudopleuronectes americanus. Biological Bulletin, vol. 129, no. 2, p. 371-387, October 1965.

149. SUND, PAUL N., AND WILLIAM J. RICHARDS
Results of trials with a neuston net in the Gulf of Guinea. Ocean Science and Ocean Engineering, Transactions of the Joint Conference, Marine Technology Society and American Society of Limnology and Oceanography, Washington, D.C., June 1965, p. 516-523.

150. SYKES, JAMES E.
Multiple utilization of Gulf Coast estuaries. Proceedings of the Seventeenth Annual Conference, Southeastern Association of Game and Fish Commissioners, Biloxi, Mississippi, September 29-October 2, 1963, p. 323-326, 1965.

151. TAYLOR, JOHN L.
Bottom samplers for estuarine research. Chesapeake Science, vol. 6, no. 4, p. 233-234, December 1965.

152. TEMPLE, ROBERT F., AND CLARENCE C. FISCHER
Vertical distribution of the planktonic stages of penaeid shrimp. Publications of the Institute of Marine Science, Texas, vol. 10, p. 59-67, June 1965.

153. THORSTEINSON, FREDRIK V.
Effects of the Alaska earthquake on pink and chum salmon runs in Prince William Sound. Proceedings of the Fifteenth Alaskan Science Conference, College, Alaska, August 31-September 4, 1964, p. 267-280, March 1965.

154. ____________________
Aftermaths of the Alaska earthquake in Prince William Sound. Pacific Fisherman, vol. 63, no. 6, p. 10-11, May 1965.

155. TUBIASH, HASKEL S., AND PAUL E. CHANLEY
Bacterial epizootics in larval and juvenile pelecypods. (Abstract) Annual Reports for 1965 of The American Malacological Union, p. 12, 1965.

156. ____________________, PAUL E. CHANLEY, AND EINAR LEIFSON
Bacillary necrosis, a disease of larval and juvenile bivalve mollusks. I. Etiology and epizootiology. Journal of Bacteriology, vol. 90, no. 4, p. 1036-1044, October 1965.

157. UKELES, RAVENNA
A simple method for the mass culture of marine algae. Limnology and Oceanography, vol. 10, no. 3, p. 492-495, July 1965.

158. UKELES, RAVENNA
Inhibition of unicellular algae by synthetic surface-active agents. Journal of Phycology, vol. 1, no. 3, p. 102-110, 1965.

159. WALLACE, DANA E., ROBERT W. HANKS, HAYES T. PFITZENMEYER, AND WALTER R. WELCH
The soft-shell clam...A resource with great potential. Marine Resources of the Atlantic Coast, Leaflet No. 3, 4 p., October 1965.

160. WALLER, RICHARD A., AND WILLIAM N. ESCHMEYER
A method for preserving color in biological specimens. BioScience, vol. 15, no. 5, p. 361, May 1965.

161. WATSON, JOHN E.
A technique for mounting and storing herring otoliths. Transactions of the American Fisheries Society, vol. 94, no. 3, p. 267-268, July 1965.

162. WEAVER, CHARLES R.
Observations on the swimming ability of adult American shad (Alosa sapidissima). Transactions of the American Fisheries Society, vol. 94, no. 4, p. 382-385, October 1965.

163. WIGLEY, ROLAND L.
Density-dependent food relationships with reference to New England groundfish. International Commission for the Northwest Atlantic Fisheries, Special Publication No. 6, p. 501-513, 1965.

164. _______________, AND ROGER B. THEROUX
Seasonal food habits of highlands ground haddock. Transactions of the American Fisheries Society, vol. 94, no. 3, p. 243-251, July 1965.

165. WILLIAMS, RICHARD B.
The interrelationship between phytoplankton and zooplankton in inshore waters near Beaufort, North Carolina. (Abstract) The Association of Southeastern Biologists Bulletin, vol. 12, no. 2, p. 55, April 1965.

166. WING, BRUCE L.
A Thalassomyces sp. (Ellobiopsidae) infesting Acanthomysis pseudomacropsis and Neomysis kadiakensis (Mysidacea) in southeastern Alaska. (Abstract) Ocean Science and Ocean Engineering, Transactions of the Joint Conference, Marine Technology Society and American Society of Limnology and Oceanography, Washington, D.C., June 1965, p. 295.

167. WOLFSON, FAY H.
The optical comparator as a tool in plankton research. Limnology and Oceanography, vol. 10, no. 1, p. 156-157, January 1965.

168. YOSHIDA, HOWARD O.
New Pacific records of juvenile albacore _Thunnus alalunga_ (Bonnaterre) from stomach contents. Pacific Science, vol. 19, no. 4, p. 442-450, October 1965.

169. ________________, AND EUGENE L. NAKAMURA
Notes on schooling behavior, spawning, and morphology of Hawaiian frigate mackerels, _Auxis thazard_ and _Auxis rochei_. Copeia, no. 1, p. 111-114, March 1965.

170. ZEIN-ELDIN, ZOULA P., AND DAVID V. ALDRICH
Growth and survival of postlarval _Penaeus aztecus_ under controlled conditions of temperature and salinity. Biological Bulletin, vol. 129, no. 1, p. 199-216, August 1965.

171. ZEIN-ELDIN, ZOULA P., AND EDWARD F. KLIMA
Effects of injected biological stains on oxygen uptake by shrimp. Transactions of the American Fisheries Society, vol. 94, no. 3, p. 277-278, July 1965.

# LIST OF
# REPORTS OF THE DIVISION OF BIOLOGICAL RESEARCH
# APPEARING IN PUBLICATIONS OF THE FISH AND WILDLIFE SERVICE - 1965

## CIRCULARS

1. AHLSTROM, ELBERT H., GERALD V. HOWARD, MAURICE BLACKBURN, JOHN L. KASK, AND GARTH I. MURPHY
   The Fishery-Oceanography Center, La Jolla, California. (Robert I. Clutter and Glenn A. Flittner, editors), U.S. Fish and Wildlife Service, Circular 232, iv + 34 p., October 1965.

2. BUREAU OF COMMERCIAL FISHERIES BIOLOGICAL LABORATORY, BEAUFORT, NORTH CAROLINA
   Annual report of the Bureau of Commercial Fisheries Biological Laboratory, Beaufort, N.C., for the fiscal year ending June 30, 1964. U.S. Fish and Wildlife Service, Circular 215, iii + 27 p., June 1965.

3. BUREAU OF COMMERCIAL FISHERIES BIOLOGICAL LABORATORY, GALVESTON, TEXAS
   Biological Laboratory, Galveston, Tex., fishery research for the year ending June 30, 1964. U.S. Fish and Wildlife Service, Circular 230, iv + 109 p., August 1965.

4. BUREAU OF COMMERCIAL FISHERIES BIOLOGICAL LABORATORY, HONOLULU, HAWAII
   Progress in 1962-63. U.S. Fish and Wildlife Service, Circular 206, i + 31 p., February 1965.

5. BUREAU OF COMMERCIAL FISHERIES RADIOBIOLOGICAL LABORATORY, BEAUFORT, NORTH CAROLINA
   Annual report of the Bureau of Commercial Fisheries Radiobiological Laboratory, Beaufort, N.C., for the fiscal year ending June 30, 1963. U.S. Fish and Wildlife Service, Circular 204, iv + 44 p., March 1965.

6. BUREAU OF COMMERCIAL FISHERIES RADIOBIOLOGICAL LABORATORY, BEAUFORT, NORTH CAROLINA
   Annual report of the Bureau of Commercial Fisheries Radiobiological Laboratory, Beaufort, N.C., for the fiscal year ending June 30, 1964. U.S. Fish and Wildlife Service, Circular 217, iii + 34 p., June 1965.

7. LOOSANOFF, VICTOR L.
   The American or eastern oyster. U.S. Fish and Wildlife Service, Circular 205, iii + 36 p., March 1965.

8. THOMPSON, J.R., AND STEWART SPRINGER
   Sharks, rays, skates, and chimaeras. U.S Fish and Wildlife Service, Circular 228, iii + 18 p., September 1965.

## COMMERCIAL FISHERIES REVIEW

1. **HESTER, FRANK, AND JOHN H. TAYLOR**
   How tuna see a net. U.S. Fish and Wildlife Service, Commercial Fisheries Review, vol. 27, no. 3, p. 11-16, March 1965. (Also as Separate No. 729.)

2. **HUNTER, CHARLES J.**
   Experimental trawling for high-seas salmon. U.S. Fish and Wildlife Service, Commercial Fisheries Review, vol. 27, no. 2, p. 1-9, February 1965. (Also as Separate No. 726.)

3. **JENSEN, ALBERT C., AND HARRIET E. MURRAY**
   The U.S. cod fishery in the northwest Atlantic. U.S. Fish and Wildlife Service, Commercial Fisheries Review, vol. 27, no. 7, p. 1-11, July 1965. (Also as Separate No. 736.)

4. **LEGUEN, J.C., F. POINSARD, AND J.P. TROADEC**
   The yellowfin tuna fishery in the eastern tropical Atlantic. U.S. Fish and Wildlife Service, Commercial Fisheries Review, vol. 27, no. 8, p. 7-18, August 1965. (Also as Separate No. 739.)

5. **TANONAKA, GEORGE K., AND JIRO NISHIMOTO**
   A Japanese gill-net fishery for bottomfish in the Gulf of Alaska. U.S. Fish and Wildlife Service, Commercial Fisheries Review, vol. 27, no. 12, p. 1-12, December 1965. (Also as Separate No. 746.)

## DATA REPORT

1. **WILLIAMSON, RICHARD S.**
   Southeastern Alaska sea surface temperatures, 1959-63. U.S. Fish and Wildlife Service, Data Report 8, i + 41 p., April 1965.

## FISHERY INDUSTRIAL RESEARCH

1. **GREEN, ROGER E., AND GORDON C. BROADHEAD**
   Costs and earnings of tropical tuna vessels based in California. Fishery Industrial Research, vol. 3, no. 1, p. 29-45, December 1965.

2. **HITZ, CHARLES R., AND ROBERT R. FRENCH**
   Occurrence of pomfret (Brama japonica) in the northeastern Pacific Ocean. Fishery Industrial Research, vol. 3, no. 1, p. 1-7, December 1965.

## FISHERY LEAFLETS

1. BUREAU OF COMMERCIAL FISHERIES, DIVISION OF BIOLOGICAL RESEARCH, WASHINGTON, D.C.
   Graduate educational grants in aquatic sciences, academic year 1966-67. U.S. Fish and Wildlife Service, Fishery Leaflet 587, 5 p., October 1965.

2. JENSEN, ALBERT C.
   Haddock. U.S. Fish and Wildlife Service, Fishery Leaflet 578, 7 p., June 1965.

## PROGRESSIVE FISH-CULTURIST

1. BAILEY, MERRYLL M.
   Lake trout fin-clipping rates at two national fish hatcheries. U.S. Fish and Wildlife Service, Progressive Fish-Culturist, vol. 27, no. 3, p. 169-170, July 1965.

2. JOERIS, LEONARD S.
   Automatic feeder for small fish held in tanks. U.S. Fish and Wildlife Service, Progressive Fish-Culturist, vol. 27, no. 3, p. 173-174, July 1965.

3. MAGNUSON, JOHN J.
   Tank facilities for tuna behavior studies. U.S. Fish and Wildlife Service, Progressive Fish-Culturist, vol. 27, no. 4, p. 230-233, October 1965.

4. MURPHY, MAUD ALICE
   A microcounting chamber. U.S. Fish and Wildlife Service, Progressive Fish-Culturist, vol. 27, no. 3, p. 176, July 1965.

## SPECIAL SCIENTIFIC REPORT--FISHERIES

1. ANDERSON, WILLIAM W., AND JACK W. GEHRINGER
   Biological-statistical census of the species entering fisheries in the Cape Canaveral area. U.S. Fish and Wildlife Service, Special Scientific Report--Fisheries No. 514, x + 79 p., July 1965.

2. FISCUS, CLIFFORD H., GARY A. BAINES, AND HIROSHI KAJIMURA
   Pelagic fur seal investigations, Alaska, 1963. U.S. Fish and Wildlife Service, Special Scientific Report--Fisheries No. 489, iv + 33 p., January 1965.

3. FISCUS, CLIFFORD H., AND HIROSHI KAJIMURA
Pelagic fur seal investigations, 1964. U.S. Fish and Wildlife Service, Special Scientific Report--Fisheries No. 522, v + 47 p., November 1965.

4. FISCUS, CLIFFORD H., AND KARL NIGGOL
Observations of cetaceans off California, Oregon, and Washington. U.S. Fish and Wildlife Service, Special Scientific Report--Fisheries No. 498, iii + 27 p., January 1965.

5. FRENCH, ROBERT R., AND ROY J. WAHLE
Salmon escapements above Rock Island Dam, 1954-60. U.S. Fish and Wildlife Service, Special Scientific Report--Fisheries No. 493, iii + 18 p., March 1965.

6. GOODING, REGINALD M.
A raft for direct subsurface observation at sea. U.S. Fish and Wildlife Service, Special Scientific Report--Fisheries No. 517, iii + 5 p., June 1965.

7. HENRY, KENNETH A.
Biological investigations of purse seine fishery for Atlantic menhaden. U.S. Fish and Wildlife Service, Special Scientific Report--Fisheries No. 519, iv + 12 p., July 1965.

8. JOHNSON, JAMES H., GLENN A. FLITTNER, AND MARVIN W. CLINE
Automatic data processing program for marine synoptic radio weather reports. U.S. Fish and Wildlife Service, Special Scientific Report--Fisheries No. 503, iv + 74 p., February 1965.

9. JUNE, FRED C.
Comparison of vertebral counts of Atlantic menhaden. U.S. Fish and Wildlife Service, Special Scientific Report--Fisheries No. 513, iii + 12 p., June 1965.

10. KEALA, BETTY ANN L.
Table of sigma-t with intervals of 0.1 for temperature and salinity. U.S. Fish and Wildlife Service, Special Scientific Report--Fisheries No. 506, i + 186 p., April 1965.

11. KLIMA, EDWARD F.
Evaluation of biological stains, inks, and fluorescent pigments as marks for shrimp. U.S. Fish and Wildlife Service, Special Scientific Report--Fisheries No. 511, iii + 8 p., May 1965.

12. LIVINGSTONE, ROBERT JR.
A preliminary bibliography with KWIC index on the ecology of estuaries and coastal areas of the eastern United States. U.S. Fish and Wildlife Service, Special Scientific Report--Fisheries No. 507, iii + 352 p., May 1965.

13. MOORE, HARRY H., AND ROBERT A. BRAEM
Distribution of fishes in U.S. streams tributary to Lake Superior. U.S. Fish and Wildlife Service, Special Scientific Report--Fisheries No. 516, iv + 61 p., July 1965.

14. NICHOLSON, WILLIAM R., AND JOSEPH R. HIGHAM, JR.
Age and size composition of the menhaden catch along the Atlantic Coast of the United States, 1961, with a brief review of the commercial fishery. U.S. Fish and Wildlife Service, Special Scientific Report--Fisheries No. 495, iv + 28 p., April 1965.

15. PACHECO, ANTHONY L., AND GEORGE C. GRANT
Studies of the early life history of Atlantic menhaden in estuarine nurseries. Part I--Seasonal occurrence of juvenile menhaden and other small fishes in a tributary creek of Indian River, Delaware, 1957-68. U.S. Fish and Wildlife Service, Special Scientific Report--Fisheries No. 504, iii + 32 p., April 1965.

16. ROITHMAYR, CHARLES M.
Industrial bottomfish fishery of the northern Gulf of Mexico, 1959-63. U.S. Fish and Wildlife Service, Special Scientific Report--Fisheries No. 518, iv + 23 p., September 1965.

17. ROPPEL, ALTON Y., ANCEL M. JOHNSON, RAYMOND E. ANAS, AND DOUGLAS G. CHAPMAN
Fur seal investigations, Pribilof Islands, Alaska, 1964. U.S. Fish and Wildlife Service, Special Scientific Report--Fisheries No. 502, v + 46 p., January 1965.

18. ROPPEL, ALTON Y., ANCEL M. JOHNSON, AND DOUGLAS G. CHAPMAN
Fur seal investigations, Pribilof Islands, Alaska, 1963. U.S. Fish and Wildlife Service, Special Scientific Report--Fisheries No. 497, v + 60 p., January 1965.

19. ROTHSCHILD, BRIAN J.
Hypotheses on the origin of exploited skipjack tuna (Katsuwonus pelamis) in the eastern and central Pacific Ocean. U.S. Fish and Wildlife Service, Special Scientific Report--Fisheries No. 512, iii + 20 p., April 1965.

20. SALOMAN, CARL H.
Bait shrimp (Penaeus duorarum) in Tampa Bay, Florida--biology, fishery economics, and changing habitat. U.S. Fish and Wildlife Service, Special Scientific Report--Fisheries No. 520, iii + 16 p., October 1965.

21. SHAW, WILLIAM N.
Seasonal gonadal cycle of the male soft-shell clam, Mya arenaria, in Maryland. U.S. Fish and Wildlife Service, Special Scientific Report--Fisheries No. 508, iii + 5 p., February 1965.

22. SYKES, JAMES E.
Bureau of Commercial Fisheries symposium on red tide. U.S. Fish and Wildlife Service, Special Scientific Report--Fisheries No. 521, iii + 11 p., September 1965.

23. TAGATZ, MARLIN E.
The fishery for blue crabs in the St. Johns River, Florida, with special reference to fluctuation in yield between 1961 and 1962. U.S. Fish and Wildlife Service, Special Scientific Report--Fisheries No. 501, iii + 11 p., February 1965.

24. THOMPSON, CLARK S., AND JOSEPH R. GAULEY
Laboratory evaluation of the 1-on-10 slope Ice Harbor fishway design. U.S. Fish and Wildlife Service, Special Scientific Report--Fisheries No. 509, iii + 20 p., June 1965.

# KINDS AND ABUNDANCE OF FISHES IN THE CALIFORNIA CURRENT REGION BASED ON EGG AND LARVAL SURVEYS[1]

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Egg and larval studies have formed an integral part the research of the La Jolla Laboratory for 25 ars. The first extensive survey cruise to determine e areal extent of sardine spawning was made in 39 in cooperation with the Scripps Institution of eanography. Subsequently we have made egg and rval surveys in 18 additional years, all in cooperan with Scripps.

Although our studies have centered on the Pacific rdine, it soon became evident that the collections we re making were equally useful in assessing the disbution and abundance of the egg and larval stages other pelagic fishes in the California Current sysn. It is this latter aspect of egg and larval studies at I wish particularly to develop in this presentan.

It is a fortunate circumstance that sardine spawn g was found to have an extensive and varying areal d temporal distribution. Because of this, our surys could not be limited to a part of the year or a part of the California Current system off Calirnia and Baja California. We had to cover an exnsive area systematically. Throughout the 1950's, g and larval surveys were conducted at approxitely monthly intervals. Only since 1961 have they n restricted to quarterly cruises.

There are perhaps three principal reasons why fish scientists conduct egg and larval surveys.

(1) For one thing, scientists are interested in the esent abundance of an adult fish population and its tribution at time of spawning, and they hope to ermine this from the distribution and abundance its pelagic eggs.

(2) Secondly, they are interested in the dynamics a fish population; in how good or poor the year ss resulting from the season's spawning will be; l in the reasons for the marked variations in sural that occur. They hope to determine this by tematically sampling the larvae and their environnt during the spawning season.

(3) They are interested in marine fish resources, ent as well as exploited, and in their distribution, ndance, and interrelations. Since the majority of es have pelagic larvae and many have pelagic s, the studies can be carried out on these stages.

There are other reasons for conducting surveys in ition to the above. Fish eggs and larvae constie only one of a number of groups of animals that ke up the zooplankton community. Some zoonkters are predators on fish eggs and larvae while ers constitute the food of developing fish larvae. Hence, our studies must include the kind and amount of zooplanktonic organisms (including biomass estimates). Of primary importance is an understanding of the physical and chemical features of the dynamic ocean environment and their influence on productivity and on the distribution and abundance of fishes.

Let us consider for a moment a few of the problems involved in using planktonic fish eggs as a means of assessing the distribution and abundance of the adult population. The developing embryos in pelagic fish eggs cannot dodge a plankton net. They can be sampled quantitatively at any given place in the ocean merely be encompassing their vertical distribution with adequate gear hauled in a uniform manner. Utilizing the information on the distribution of eggs, the areal distribution of adult fish at time of spawning can be determined with considerable precision. The basic requirements are (1) extensive enough coverage in space to completely delimit the areal distribution of spawning and (2), surveys repeated at frequent enough intervals to delimit the spawning season in the several parts of a species' range. Delimiting the areal and seasonal distribution of spawning is a straightforward reconnaisance problem.

Estimating the amount of spawning within acceptable limits of precision is another matter, however. This is a far more difficult problem, as it involves the manner in which fish are distributed at time of spawning, the extent of spawning patches, the rate of diffusion of eggs away from such patches and many other variables that probably will differ for each species of fish being investigated. Our yearly estimates of sardine egg abundance are consistent enough to lend support to the determination that the fiducial limits for our annual egg estimates are roughly half or double.

Furthermore, if surveys were limited to this one aspect, it would be possible to devise sampling techniques that would increase reliability of sampling. We demonstrated that horizontal strip sampling along cruise tracks using a series of high speed samplers is an excellent way of integrating the patchy distribution of sardine eggs over area (Ahlstrom *et al.* 1958). We did not adopt this technique routinely because high speed samples were of limited value in collecting fish larvae. The volume of water strained was just too small to get an adequate size sampling of larvae. Even when employing only oblique plankton hauls made with our CalCOFI net, reliability of egg estimates can be enhanced by increasing the frequency of sampling within known spawning areas.

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gures 1–15 appear at end of paper, pages 38 to 52.

We have found that estimates of larval abundance are more consistent than estimates of egg abundance. This is an interesting point, as it is often assumed that the reverse is true. In fact this latter opinion was expressed by Alan Saville in a review paper on egg and larval studies that he contributed to the ICES symposium at Madrid in 1963. I will present data to substantiate this point later in my talk.

Larval estimates are assumed to be less reliable than egg estimates when they are used for estimating the relative abundance of the various pelagic species spawning in an area. There is an element of truth in this. Considerable mortality has been experienced during both the embryonic and larval stages—and it must differ from species to species.

There are a number of advantages to using larvae in preference to eggs and none is more convincing than the following: larvae can be identified with more certainty. I need only mention the similarity in appearance of early stage gadid eggs that has plagued studies on the haddock or the difficulty that Tom English had in separating the early stage eggs of three species of flatfish so that he did his studies on reliability of estimates of egg abundance on composite samples of all three.

Then too there are more species represented as larvae than as eggs. Some fishes incubate their eggs and extrude them only when they hatch. There are some 50 species of *Sebastodes* in California waters that are ovoviviparous, and some other fishes including *Brosmophycis*. Larvae of various species with demersal eggs also occur in the plankton; the Pacific herring, osmerid smelts, and cultus cod are examples.

There is another advantage for using larvae for estimates of abundance that appears to me to be of prime importance. The eggs of many of our common species—sardine, jack mackerel, Pacific mackerel hatch in 2 to 4 days at the temperatures usually prevailing in our waters. Hence, only as many days spawning can be represented in our collections. Larvae, however, require a month or more to develop through the size range we take in our samples. Thus a larval sample represents, in a real sense, an integration over time. With cruises spaced at monthly intervals larval numbers should adequately reflect the sequence of spawning. Another consequence of this accumulation is that larvae tend to be more widely distributed than eggs and hence taken in more collections.

I do not intend to go into the subject of larval survival to any extent. John Isaacs discusses this subject with respect to the sardine and anchovy in this symposium. A few aspects of this problem will be presented in a latter part of this paper.

Now that I have presented the case for using larvae, I will get to the main thesis of my talk, which is simply this; there is no better technique available for fish resource evaluation than systematic larval surveys.

I will remark to begin with that I am impatient with the often used excuse that such surveys are impractical because of the difficulty of identifying larval fish. There also are difficulties in identifying copepods, medusae and most other groups in marine plankton. This has not prevented a number of scientist from becoming quite competent in the taxonomy o such planktonic groups. It is just one of the facts o life that a taxonomist has to expend rather considerable time and effort in learning his trade. Larva fish taxonomy is not a task to assign to a junior fisher biologist without experience in taxonomy.

It is very difficult to evaluate the kind and amoun of our adult fishery resources. Bottom trawls coul be used to collect a segment of the fish biomass, midwater trawls another fraction, long-lines another, et This is because fish are so various with respect to size depth distributions, behavior patterns, food habits etc. Juvenile and adult fishes possess one characteristi in common, agility. This characteristic has led us t class fish as nekton.

Fishes are passive, however, or only moderatel agile during their early development stages as embryos and larvae. Pelagic fish eggs and larvae are temporary members of the plankton community and ca be sampled by plankton gear. The sampling problen of fish eggs and larvae is orders of magnitude mor simple than with juvenile and adult fishes. It is possible to use fish eggs and especially fish larvae for resource evaluation because most marine fishes have pelagic larval stage. The majority of pelagic fishe spawn their eggs in the open sea in a manner tha permits each egg to be a separate, free-floating entity Egg masses are the exception in the pelagic realm an only a few fishes like the flying fishes and atherinid spawn their eggs with strings attached.

At the risk of being repetitious, I will restate severa points made previously. Ovoviviparous fishes, such a rockfish, coddle their embryos, but extrude their newl hatched larvae to fend for themselves in the ope sea. The larvae of many fishes with demersal eggs become members of the plankton community. Onl sharks and their relatives and a few marine teleos groups such as embiotocids completely bypass th planktonic larval stage.

The eggs and larvae of the majority of pelagic fishe have a relatively shallow depth distribution, occurrin principally in the upper mixed layer. On CalCOF survey cruises, we haul our plankton nets obliquel from about 140 meters deep to the surface. This dept of haul is enough to completely encompass the vertical distribution of most of our common fish larva including sardine, anchovy, Jack mackerel, Pacifi mackerel and rockfish.

On Norpac, the wide-ranging survey of the nort Pacific made in August 1955, we sampled two dept levels, the usual upper level between 0–140 meters an the adjacent level between 140 and 280 meters. Onl about ⅙ as many larvae were taken in the deeper leve as in the upper; fully half of these were hatchet fis larvae, a group seldom taken in the upper level.

I have reached the point in my talk at which would like to present several kinds of informatio simultaneously. These data are concerned with thre things: kinds of fish larvae taken in our surveys, thei numerical abundance, and their distributions.

I can cover the first item, kinds of larvae, very suc- ıtly. There are many kinds of fish larvae in the Cali- rnia current area. Some are abundant, some are com- on, many more are rare. Over the years we have ken some hundreds of kinds of fish larvae.

When tabulating the numbers of larvae taken dur- g a cruise or season, we soon noticed that most of e larvae belonged to relatively few kinds. By kind am referring to species in most instances, but some- nes to genus.

Our data are most completely analyzed for the ars 1955 through 1958. During these four years, 12 nds of larvae made up between 90 and 93% of the rvae collected. These 12 kinds include two genera d 10 species. In three of the four years the same kinds of larvae were the most abundant numeri- lly, and in the remaining year, 1956, there were 2 splacements.

Of the 12 kinds of fishes that are consistently abund- t as larvae, 6 are of present or potential commercial portance, 6 have no foreseeable commerical use. All must be important in the food web.

The larvae making up the second group of 12 kinds, i.e., the larvae ranking between 13th and 24th in abundance, contributed 4.3 to 5.5% of the total during 1955 through 1958. Abundance of larvae of the more common species is summarized in Table 1.

The remainder, after both of the above categories are taken into account, constitutes as little as 2.7% of the total in 1955, 4.3% in 1958, 4.6% in 1956 and 5.5% in 1957.

It should be evident from the above groupings that a great deal could be learned about the fish resources of an area without identifying every larva. If only the larvae of the 25 most common kinds of fishes were known, for example, a name could be given to 19 out of every 20 larvae collected on our surveys. From the standpoint of biomass, these are the larvae of the fishes that will make up most of it.

I'm not suggesting that one's attention be limited to the common kinds of larvae. Far from it; many of the fishes of greatest interest to the larval taxonomist are in the 5% remainder, including some important apex predators.

TABLE 1

MPARISON OF RELATIVE ABUNDANCE OF FISH LARVAE IN THE CALIFORNIA CURRENT REGION BASED ON YEARLY SUMMARIES OF NUMBER OF LARVAE OBTAINED IN PLANKTON COLLECTION FROM CalCOFI SURVEY CRUISES 1955–1958

| | 1955 | | | 1956 | | | 1957 | | | 1958 | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | No. Taken | % of Total | Rank* | No. Taken | % of Total | Rank* | No. Taken | % of Total | Rank* | No. Taken | % of Total | Rank* |
| raulis mordax | 140,183 | 39.03 | 1 | 134,931 | 33.05 | 1 | 146,631 | 29.70 | 1 | 205,457 | 45.21 | 1 |
| luccius productus | 60,090 | 16.73 | 2 | 94,277 | 23.10 | 2 | 78,283 | 15.86 | 2 | 58,368 | 12.84 | 2 |
| astodes spp. | 29,344 | 8.17 | 3 | 29,144 | 7.14 | 3 | 36,473 | 7.39 | 4 | 23,931 | 5.27 | 4 |
| arichthys spp. | 20,411 | 5.68 | 4 | 23,635 | 5.79 | 4 | 15,813 | 3.20 | 9 | 6,655 | 1.46 | 11 |
| roglossus stilbius | 15,111 | 4.21 | 5 | 18,620 | 4.56 | 5 | 29,506 | 5.98 | 5 | 4,859 | 1.07 | 12 |
| linops caerulea | 14,121 | 3.93 | 6 | 15,523 | 3.80 | 6 | 9,833 | 1.99 | 11 | 11,423 | 2.51 | 7 |
| churus symmetricus | 13,246 | 3.69 | 7 | 8,027 | 1.97 | 10 | 20,006 | 4.05 | 6 | 6,409 | 1.41 | 10 |
| panyctus mexicanus | 13,165 | 3.67 | 8 | 10,802 | 2.65 | 8 | 16,207 | 3.28 | 8 | 16,514 | 3.63 | 5 |
| ciguerria lucetia | 12,654 | 3.52 | 9 | 9,832 | 2.41 | 9 | 55,114 | 11.17 | 3 | 55,756 | 12.27 | 3 |
| panyctus leucopsarus | 7,454 | 2.08 | 10 | 15,125 | 3.71 | 7 | 16,808 | 3.40 | 7 | 11,892 | 2.62 | 6 |
| genichthys laternatus | 4,771 | 1.33 | 11 | 3,158 | 0.77 | 13 | 11,603 | 2.35 | 10 | 7,061 | 1.55 | 8 |
| hylagus wesethi | 3,245 | 0.90 | 12 | 2,146 | 0.52 | 17 | 6,347 | 1.29 | 12 | 7,021 | 1.54 | 9 |
| panyctus ritteri | 1,988 | 0.55 | 13 | 1,924 | 0.47 | 18 | 2,789 | 0.56 | 14 | 3,091 | 0.68 | 13 |
| umatophorus diego | 1,950 | 0.54 | 14 | 1,520 | 0.37 | 20 | 1,865 | 0.38 | 18 | 1,273 | 0.28 | 20 |
| trona spp. | 1,823 | 0.51 | 15 | 1,852 | 0.45 | 19 | 1,415 | 0.29 | 22 | 1,775 | 0.39 | 15 |
| hylagus ochotensis | 1,301 | 0.36 | 18 | 2,231 | 0.55 | 15 | 1,078 | 0.22 | 25 | 1,550 | 0.34 | 16 |
| amphaes spp. | 775 | 0.22 | 25 | 1,051 | 0.26 | 24 | 1,328 | 0.27 | 24 | 1,255 | 0.28 | 21 |
| lothone spp. | 1,532 | 0.43 | 16 | 814 | 0.20 | | 2,880 | 0.58 | 13 | 2,795 | 0.62 | 14 |
| letonbeania crenularis | 999 | 0.28 | 21 | 3,352 | 0.82 | 12 | 1,570 | 0.32 | 21 | 526 | 0.12 | |
| entina sialis | 832 | 0.23 | 24 | 1,288 | 0.32 | 22 | 1,400 | 0.28 | 23 | 276 | 0.06 | |
| notus spp. | | | | 2,470 | 0.60 | 14 | 2,731 | 0.55 | 15 | 1,307 | 0.29 | 19 |
| odus spp. | 641 | 0.18 | | 958 | 0.23 | 25 | 2,338 | 0.47 | 17 | 1,219 | 0.27 | 23 |
| ronichthys spp. | 1,038 | 0.29 | 19 | 1,118 | 0.27 | 23 | 579 | 0.12 | | 164 | 0.04 | |
| hus theta | 1,022 | 0.28 | 20 | 3,562 | 0.87 | 11 | 713 | 0.14 | | 588 | 0.13 | |
| oscion spp. | 860 | 0.24 | 23 | 104 | 0.02 | | 31 | 0.06 | | 1,350 | 0.30 | 18 |
| phurus atricauda | 73 | 0.02 | | 1,373 | 0.34 | 21 | 1,603 | 0.32 | 20 | 222 | 0.05 | |
| toscopelus townsendi | 446 | 0.12 | | 222 | 0.05 | | 2,598 | 0.53 | 16 | 1,109 | 0.31 | 17 |
| bolophorus californiense | 653 | 0.18 | | 462 | 0.11 | | 1,645 | 0.33 | 19 | 1,236 | 0.27 | 22 |
| thys lockingtoni | 1,385 | 0.39 | 17 | 898 | 0.22 | | 768 | 0.16 | | 438 | 0.10 | |
| meta simillima | 933 | 0.26 | 22 | 611 | 0.15 | | 797 | 0.16 | | 114 | 0.02 | |
| agonurus spp. | 490 | 0.14 | | 2,154 | 0.53 | 16 | 708 | 0.14 | | 60 | 0.01 | |
| nias atriventer | 411 | 0.11 | | 81 | 0.02 | | 271 | 0.05 | | 1,188 | 0.26 | 24 |
| ophum spp. | 400 | 0.11 | | 223 | 0.05 | | 795 | 0.16 | | 993 | 0.22 | 25 |
| thers | 5,808 | 1.62 | | 14,652 | 3.60 | | 21,023 | 4.26 | | 16,280 | 3.58 | |
| AL | 359,155 | 100.00 | | 408,140 | 100.00 | | 493,549 | 100.01 | | 454,455 | 100.00 | |

ınk includes only first 25.

I wish to discuss the top 12 for a few moments. Larvae of the northern anchovy consistently have been the most numerous in the CalCOFI survey area; hake larvae have been consistently ranked second in abundance. Neither of these species is fished to any extent. They represent potential fishery resources. Larvae of Pacific sardine, jack mackerel, rockfish (*Sebastodes spp.*) and sanddabs (*Citharichthys spp.*) are the other 4 kinds that represent present or potential commercial resources.

The six species with no forseeable commercial importance are the gonostomatid, *Vinciguerria lucetia,* two deep sea smelts, *Leuroglossus stilbius* and *Bathylagus wesethi,* and three myctophid lantern fish, *Lampanyctus leucopsarus, Lampanyctus mexicanus* and *Diogenichthys laternatus.* There can be little doubt about the ecological importance of these six.

Illustrations (Figs. 1–10) are included here of the larvae of fishes making up the top 12, and of the larvae of a half-dozen other species. Species having elongated, thread-like larvae are grouped in figures 1 and 2. These all are (larvae of) isospondylous fishes. The five species illustrated, listed in their descending order in the two plates are: 1) larvae of the Pacific sardine (*Sardinops caerulea*), 2) larvae of the northern anchovy (*Engraulis mordax*), 3) larvae of the gonostomatid lantern fish, *Vinciguerria lucetia,* 4) larvae of the deep sea smelt, *Leuroglossus stilbius* and 5) larvae of another deep sea smelt, *Bathylagus wesethi.* The two tones of background shading are indicative of the depth zone in which the larvae predominantly occur. The light shading indicates distribution in the upper mixed layer, the darker shading indicates that the species occurs mostly below the thermocline. All of these species rank among the top 12 in abundance. The larvae of the two deep sea smelts have not been illustrated previously.

Our plankton hauls routinely sample the complete depth distribution of larvae of the upper mixed layer, but do not necessarily sample the complete depth distributions of the larvae that occur most commonly in and below the thermocline (dark shading). The marked decrease in abundance of *Leuroglossus* in collections made during 1958 for example, may be due in part, to less complete depth sampling during this ''warm-water'' year.

The larvae of 3 of the 4 species illustrated in Figures 3 and 4 are of present or potential commercial importance. These larvae as a group are deeper bodied and have larger heads than the larvae in Figures 1 and 2. The top species is a pomacentrid, the blacksmith, *Chromis punctipinnis.* The larvae of this species are moderately common, but *Chromis* does not rank among the top two dozen kinds. The larvae of the next species illustrated, Pacific mackerel, ranked between 14th and 20th in abundance during the 4-year period, 1955 to 1958. The early development of this species was described in detail by Kramer (1960). The third species in these figures, the carangid, *Trachurus symmetricus,* known commercially as the jack mackerel, is one of the abundant kinds of larvae in the CalCOFI area. The bottom illustrations are of the deeper-dwelling larvae of hake, which occur mostly below the thermocline. The embryonic and larval development of jack mackerel was described by Ahlstrom and Ball (1954), and of hake by Ahlstrom and Counts (1955).

Larvae of seven species of myctophid lantern fishes are illustrated in Figures 5 to 7. Figures 5 and 6 illustrate larvae of the same group of species at different sizes. These are: *Lampanyctus leucopsarus, Lampanyctus mexicanus, Lampanyctus ritteri, Symbolophorus (Myctophum) californiense, Tarletonbeania crenularis.* The larvae of *Lampanyctus leucopsarus* and *L. mexicanus* are shaped rather similarly, but differ in ventral pigmentation and larger larvae of *L. mexicanus* possess a dorsal adipose spot lacking in *L. leucopsarus.* Both differ rather markedly from the larvae of *L. ritteri,* which have the deep stubby body shape that is more characteristic of the genus *Lampanyctus.* The interesting larvae of *Symbolophorus californiense* are moderately stalk-eyed, while the large larvae of *Tarletonbeania crenularis* develop an envelope-like fin fold.

Larvae of *Diogenichthys atlanticus* and *D. laternatus* are illustrated in Figure 7. Larvae of the latter species occur in abundance in the southern part of the CalCOFI area. *D. atlanticus* is only moderately common; it is distributed to the north of *D. laternatus,* with some overlap off central Baja California. These two species are very similarly pigmented but *D. atlanticus* has a barbel, making it unique in this character among myctophid larvae.

Five species of sanddabs *(Citharichthys spp.)* occur in the CalCOFI survey area. Three of the more common species are shown in Figures 8 and 9. The more northerly distributed sanddabs are *Citharichthys stigmaeus* (upper) and *C. sordidus* (middle). *C. xanthostigma* larvae occur in abundance off central Baja California, In bothid flatfish it is usual to have one or more anterior dorsal and pelvic rays elongated. Note that larger larvae of *C. sordidus* and *C. xanthostigma* have two elongated anterior dorsal rays (actually the 2nd and 3rd anterior rays) and two correspondingly elongated pelvic rays. The other 2 species of *Citharichthys* in the CalCOFI area, *C. fragilis* and *C. gilberti* also possess this larval character. Hence *C. stigmaeus* is the more unusual in lacking such elongated rays at all larval sizes. It also develops much less pigmentation than any of the other species of *Citharichthys.*

Larvae of rockfish *(Sebastodes spp.)* are illustrated in Figure 10. *Sebastodes* contains many more species than any other genus in the eastern Pacific, over 50 in California waters. Because of this complexity, very few larval series have been established as yet for individual species. An exception is *Sebastodes paucispinis,* whose larvae are figured in the lower half of this plate. This species develops elongated pectoral and pelvic fins, which are rather heavily pigmented near their tips. The paired occipital spines, on the back of the head, sometimes bifurcate, are characteristic of rockfish larvae.

Another aspect of egg and larval surveys that is of prime importance in resource evaluation is the information obtained on distribution. Before Cal-

)FI little was known about the distribution of jack ıckerel, for example. The CalCOFI surveys soon owed that jack mackerel eggs and larvae occurred roughout the CalCOFI area. Larvae were taken as r seaward as the cruises extended. On Norpac, jack ıckerel eggs and larvae were taken 1100 miles at sea Washington. There seems little doubt that jack ıckerel is an oceanwide resource in the temperate rth Pacific.

The southward extent of the distribution of jack ıckerel eggs and larvae is adequately delimited by r cruises but not the offshore or northward extents. ıe southern boundary shifts in response to changing eanographic conditions, as is illustrated by the more ıthward extent of jack mackerel larvae in 1954 'ig. 11B) as co-mapped to 1958 (Fig. 11A).

Hake furnishes another example. Hake larvae con-tently have been the second most abundant kind in lCOFI collections, exceeded only by anchovy lar-e. Hake eggs and larvae are almost as widespread the CalCOFI survey area as jack mackerel (Fig. C). Adult hake apparently move offshore to spawn, d return to the area of the continental slope after awning.

Distribution of larvae of rockfish (Fig. 12B) and nddabs (Fig. 12C) represent the composite distri-tions of a number of species; 5 in *Citharichthys,* to 50 in *Sebastodes.* Both genera have a greater 'shore extent than is anticipated for near bottom velling fishes. This offshore distribution is a con-tent phenomenon, occurring in all years covered our investigations.

Species with tropical-subtropical distribution ex-nd varying distances to the north depending in part the species, in part on hydrographic conditions. *ıciguerria lucetia,* perhaps the most abundant fish rvae in the tropical eastern Pacific, is distributed far north as Point Conception, California in most ars (Ahlstrom and Counts 1958, Figs. 18 and 19) d off central California in favorable seasons (Fig. A). The distribution of this species in the CalCOFI ea constitutes but a fraction of its distribution in e eastern Pacific (Ahlstrom and Counts 1958 Fig. ).

Another abundant tropical-subtropical species with equally extensive distribution is *Diogenichthys ernatus* (Fig. 13A). On Shellback Expedition, vae of this species were by far the most abundant ctophid larvae in the eastern tropical Pacific. In ost years this species extends as far north as off . San Eugenio, central Baja California, but in fa-rable (warmer) years it can reach southern Cali-nia. Hence the distribution of this species in the lCOFI area constitutes only the northern portion extensive range. The area of distribution of *D. at-ıticus* is in offshore oceanic waters off central d southern Baja California and in the portion of e CalCOFI area lying between Pt. San Eugenio and n Francisco, California. It is a much less abundant ecies than its close relative (Fig. 13B).

Two myctophids having subarctic-temperate distri-tions are *Tarletonbenia crenularis* (Fig. 13C) and *mpanyctus leucopsarus* (Fig. 14C). Larvae of such temperate water species occur in greatest abundance during the colder season of the year—winter and spring; larvae of the subtropical myctophid, *Lampanyctus mexicanus* (Fig. 14B) are rare in winter collections, and build to a peak during the summer cruises. The distribution of this species is more restricted than that of many other myctophids, hence the area shown probably constitutes a larger portion of the total distribution of this species in the eastern north Pacific exclusive of the Gulf of California than for such species as *Lampanyctus ritteri* (Fig. 14A) or *Lampanyctus regalis* (distribution not illustrated). Within its area of occurrence, however, it is probably the most abundant myctophid present.

The most abundant of the deep sea smelts is *Leuroglossus stilbius.* It is as widely distributed in the CalCOFI area as jack mackerel or hake (Fig. 15C). Furthermore it is widely distributed in the Gulf of California, and as a matter of interest was initially described from Gulf material. Incidentally in some groups of fishes the differences between larvae of the several species are more striking than differences between adult fishes. The deep sea smelts are one such group. Although larvae of *Bathylagus wesethi* are abundant enough to put it among the top 12, it has a somewhat circumscribed distribution (Fig. 15A) being replaced in the north by *Bathylagus ochotensis* and to the south by *Bathylagus nigrigenys.* The distribution of *B. ochotensis* is shown in Figure 15B. This species is very widely distributed in the north Pacific in subarctic to temperate waters. Some of this wider distribution is shown in Figure 16. This figure summarizes the distribution of bathylagid and argentinid fishes in the part of Norpac that was covered by CalCOFI vessels in August 1955. Note the offshore occurrences of *Bathylagus ochotensis* and the more circumscribed distribution of *B. wesethi. Leuroglossus* is principally a winter and spring spawner and this is undoubtedly why there are so few occurrences during Norpac which was made during August.

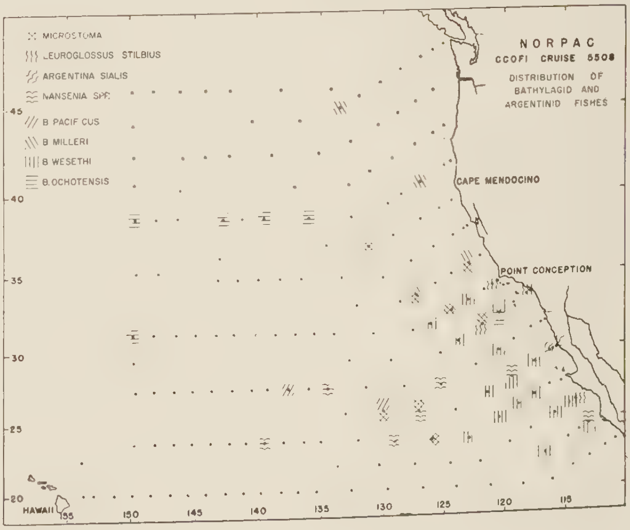

**FIGURE 16.** Distribution of larvae of Bathylagids and Argentinids on Norpac.

We obtained such excellent information on distributions of fish larvae on Norpac, that I consider this the most important survey made during the history of CalCOFI. Despite its value, it so far has been only a one-time thing. There is nothing I would like better than to see Norpac repeated at the other seasons of the year, especially in February–March when hake spawning is at its peak, and in May–June when jack mackerel spawning is at its peak.

As I mentioned at the beginning of my presentation, the sardine has been the pivotal species in our studies. We have circumscribed its spawning distribution and in doing this have largely circumscribed the spawning distributions of other important wetfishes, including the anchovy and the Pacific mackerel.

One of the important things that we have learned about the distribution of fish at spawning is that it varies from season to season. There is no such thing as fixed spawning areas for pelagic fish in the California Current system. The only way to outguess the fish is to sample so widely that you are bound to fence them in. The marked differences in spawning distribution that can occur in adjacent years is most strikingly shown by the spawning distribution of sardines in 1953 and 1954 (for distributional charts refer to Ahlstrom, 1959). In 1953, sardine spawning was mainly restricted to central Baja California, with only about 1% occurring off California. In 1954 the fish reinvaded California in numbers, having a very widespread spawning distribution. The 1954 spawning has an areal extent that is nearly 2½ times as great as spawning distribution in 1953.

In such years as 1954 and 1955, sardine spawning was more widely distributed off southern California than anchovy, especially in offshore water. There was a zone offshore in which sardine larvae occurred alone. The pattern was repeated in several years, and I began to consider it characteristic of sardines to move fairly far offshore to spawn. Anchovies didn't appear to be so venturesome.

In recent years, larval abundance of anchovies has continued to increase. Anchovy larvae, instead of being only 3.3 times as numerous as sardine larvae in 1951 became over 9 times by 1955 and nearly 24 times by 1958. Since then the disproportion has further increased until it was approximately 80 to 1 in 1962, as determined from the four quarterly cruises made in that year.

With the changes in abundance, the spawning distribution of the 2 species markedly altered. The moderate sardine spawning remaining is concentrated inshore. Anchovy larvae are now abundant in the offshore waters of southern California, as well as in inshore waters. In fact they seem to be everywhere. Anchovy larvae co-occur in nearly all hauls containing sardine larvae—94% of the hauls in 1958, 98% in 1962. There were 6 anchovy larvae for each sardine in co-occurrence hauls in 1962.

It is because of the information gained on egg and larval surveys that we have been able to document the increase in the anchovy population. The anchovy is but little fished commercially; only 1382 tons were landed in 1962 and another 6000 or 7000 tons were used for bait by sportfishermen. Hence the fishery yields little information on the state of the anchovy resource.

The numbers of anchovy larvae that were taken on CalCOFI surveys during 1952 through 1959 are given in Table 2.

TABLE 2

**ABUNDANCE OF ANCHOVY LARVAE**

| | *Census estimates* × 10 ⁸ |
|---|---|
| 1951 | 15,100 |
| 1952 | 17,070 |
| 1953 | 23,680 |
| 1954 | 38,410 |
| 1955 | 37,660 |
| 1956 | 38,510 |
| 1957 | 40,440 |
| 1958 | 56,930 |
| 1959 | 54,170 |

I am using estimates that take unequal spacing of stations into account; and designate them as "census estimates".

The anchovy population more than doubled in size between 1951 and 1954 and trebled in size by 1958. The anchovy population is even larger in 1962 and 1963. We presently are conducting only quarterly surveys, but on these anchovy larvae are as numerous as all other fish larvae combined. We have been impressed by the consistency of our anchovy data.

| | *No. hauls taken* | *Occurrences of anchovy* | *Ave. no. per haul* | *Ave. no. per positive haul* |
|---|---|---|---|---|
| 1954 | 1474 | 758 | 109 | 213 |
| 1955 | 1375 | 616 | 102 | 218 |
| 1956 | 1397 | 536 | 97 | 252 |
| 1957 | 1493 | 580 | 98 | 253 |
| 1958 | 1853 | 778 | 111 | 264 |

For example, between 1954 and 1958 the average number of anchovy larvae per haul made in the CalCOFI area, was 109 in 1954, 102 in 1955, 97 in 1956, 98 in 1957 and 111 in 1958, a range fo from 97 to 111. The figures are based on all hauls taken, whether anchovy larvae were present or not. When only positive hauls are considered, the average number per haul increased somewhat between 1954 and 1958. In 1954 it was 213 larvae, then in succeeding years 218, 252, 253 and 264—15% more larvae were taken per positive haul in 1958 than in 1954.

One reason for the consistency in the above figures is that we sample about the same proportion of large concentrations of anchovy larvae, moderate concentrations, etc., during each season. During 1954–1958, the proportion of hauls containing few to many larvae were as follows:

Hauls containing 1 to 10 larvae: 24 to 29% of positive hauls

Hauls containing 11 to 100 larvae: 30 to 42% of positive hauls

Hauls containing 101 to 1000 larvae: 25 to 33% of positive hauls

Hauls containing over 1000 larvae: 5.5 to 7.5% of positive hauls

We report on the size composition of anchovy larval mples. For ready comparison the larvae are grouped about 3 mm intervals:

| | *Percent of seasonal total in size categories* | | | | |
|---|---|---|---|---|---|
| | *1954* | *1955* | *1956* | *1957* | *1958* |
| 50– 5.75 | 60.3 | 60.3 | 48.4 | 55.8 | 62.3 |
| 75– 8.75 | 28.1 | 27.2 | 32.7 | 29.8 | 25.6 |
| 75–11.75 | 8.8 | 9.7 | 15.4 | 11.5 | 9.1 |
| 75–14.75 | 2.14 | 2.01 | 2.77 | 2.28 | 2.26 |
| 75 & larger | 0.57 | 0.68 | 0.64 | 0.62 | 0.66 |

There were about the same proportion of larvae of ifferent sizes during the five years. This as a gratify-g result, for if the proportion of larvae of different zes is about constant, then estimates based on total umber of larvae are quite meaningful.

But there is one aspect of the above that isn't as ratifying. We had hoped to be able to distinguish etween good and poor year classes of fishes by dif-erences in survival of larvae. The survival curves for nchovy larvae are surprisingly similar from year year. This uniformity can be seen by looking at e proportion of larger lervae that were present in e 1954–1958 samples. Larvae 15.75 mm and larger onstituted 0.57% of the total in 1954, 0.68% in 1955, 0.64% in 1956, 0.62% in 1957, 0.66% in 1958. A similar uniformity is found in our sardine larval summaries. I am just pointing this fact up, not trying to develop it here. It is a problem that will have to be dealt with separately.

## REFERENCES

Ahlstrom, E. H., 1959. Distribution and abundance of eggs of the Pacific sardine, 1952–1956. *U.S. Fish and Wild. Serv., Fish. Bull.*, 60 (165) : 185–213.

Ahlstrom, E. H., and O. P. Ball, 1954. Description of eggs and larvae of jack mackerel *(Trachurus symmetricus)* and distribution and abundance of larvae in 1950 and 1951. *U.S. Fish and Wild. Serv., Fish. Bull.*, 56 (97) : 209–245.

Ahlstrom, E. H., and R. C. Counts, 1955. Eggs and larvae of the Pacific hake, *Merluccius productus. U.S. Fish and Wild. Serv., Fish. Bull.*, 56 (99) : 295–329.

Ahlstrom, E. H., and R. C. Counts, 1958. Development and distribution of *Vinciguerria lucetia* and related species in the Eastern Pacific. *U.S. Fish and Wild. Serv., Fish Bull.*, 58 (139) : 363–416.

Ahlstrom, E. H. , J. D. Isaacs, J. R. Thraikill and L. W. Kidd, 1958. A high-speed plankton sampler. *U.S. Fish and Wild. Serv., Fish. Bull.*, 58 (132) : 187–214.

Kramer, D., 1960. Development of eggs and larvae of Pacific mackerel and distribution and abundance of larvae 1952–56. *U.S. Fish and Wild. Serv., Fish. Bull.*, 60 (174) : 393–438.

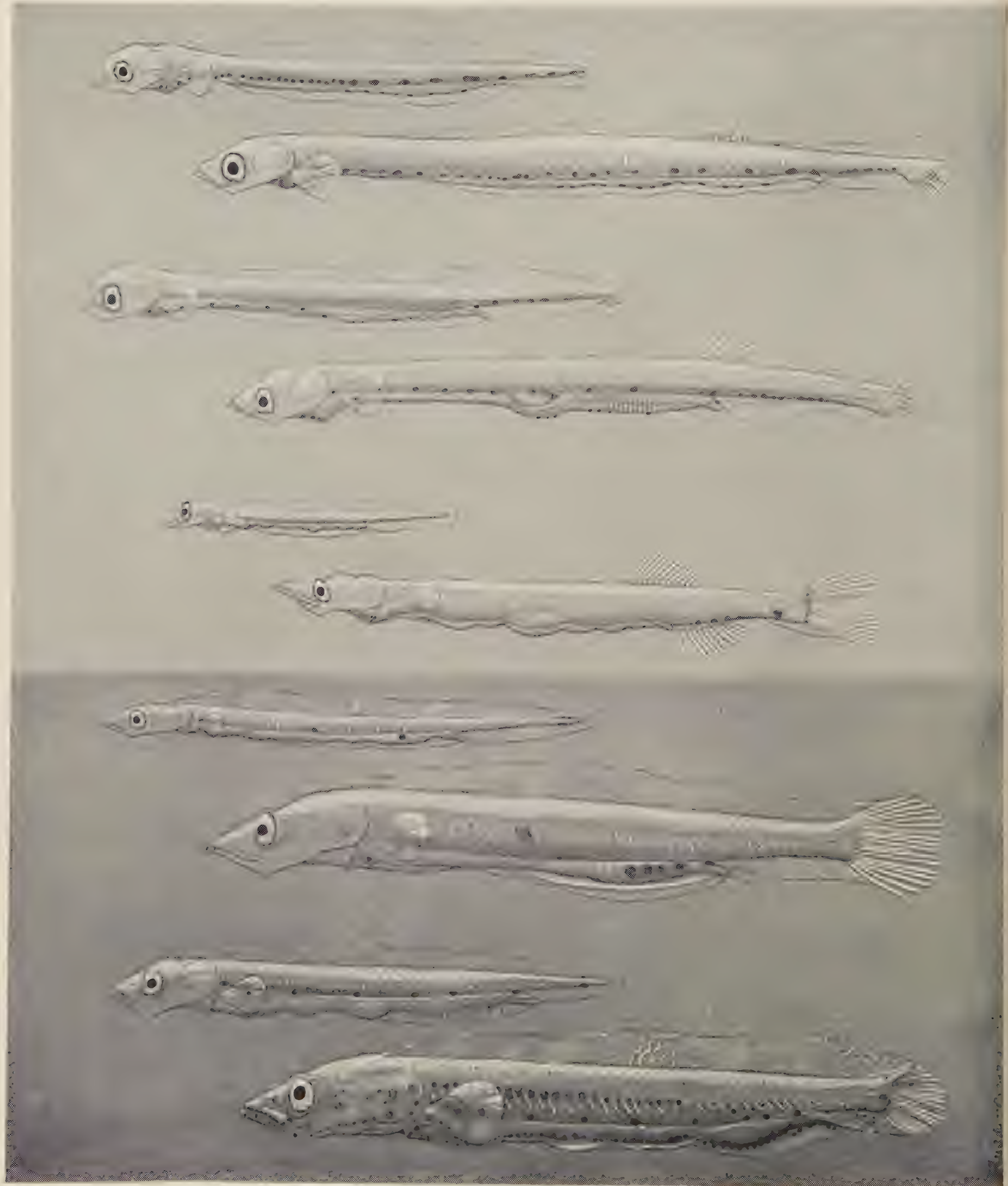

FIGURE 1. From top to bottom—*Sardinops caerulea* 5.6mm–12.5mm; *Engraulis mordax* 6.0mm–11.5mm; *Vinciguerria lucetia* 3.2mm–9.0mm; *Leuroglossus stilbius* 5.4mm–15.7mm and *Bathylagus wesethi* 5.7mm–11.3mm.

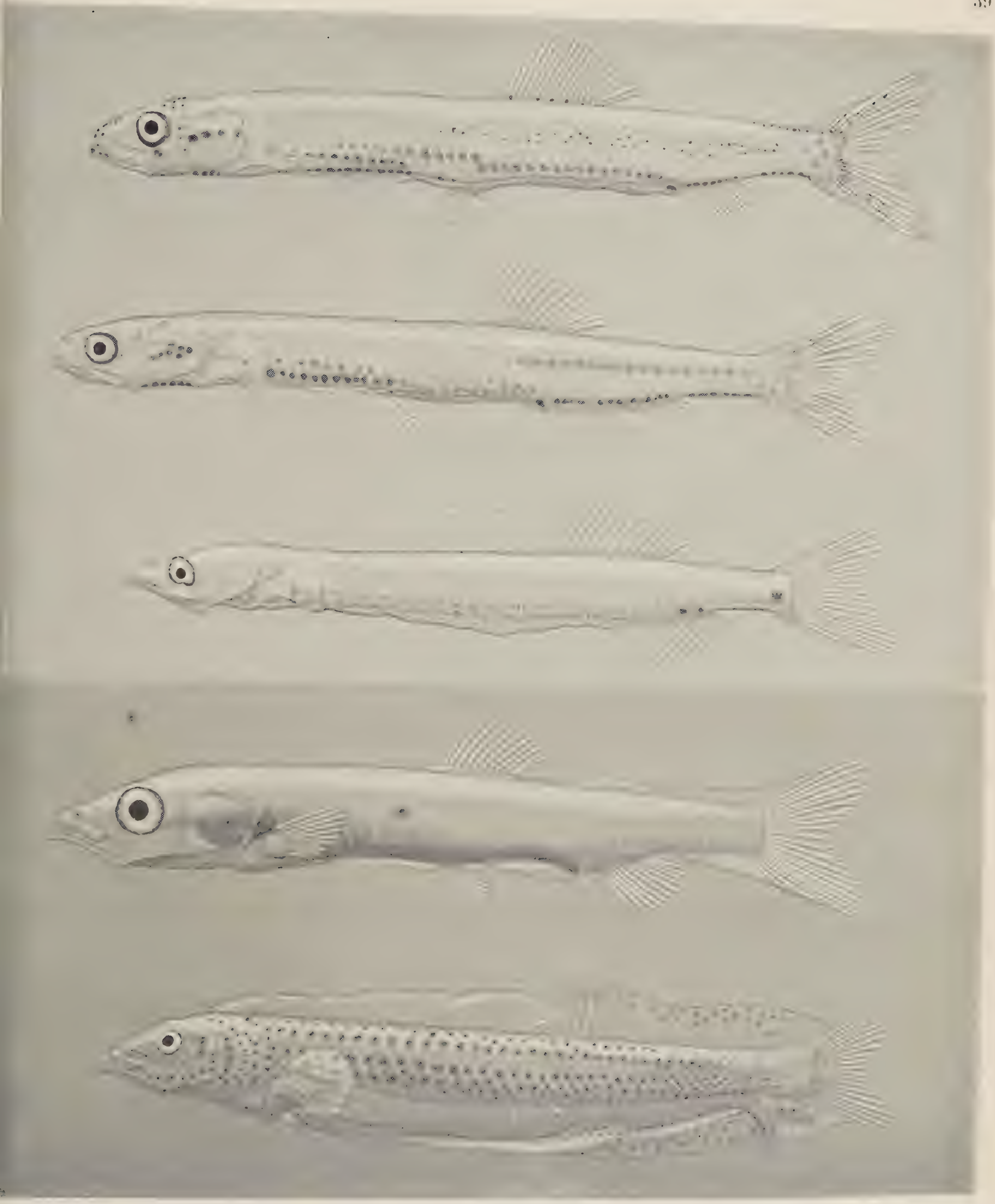

FIGURE 2. From top to bottom—*Sardinops caerulea* 31.3mm; *Engraulis mordax* 31.0mm; *Vinciguerria lucetia* 15.0mm; *Leuroglossus stilbius* 28.5mm and *Bathylagus wesethi* 24.5mm.

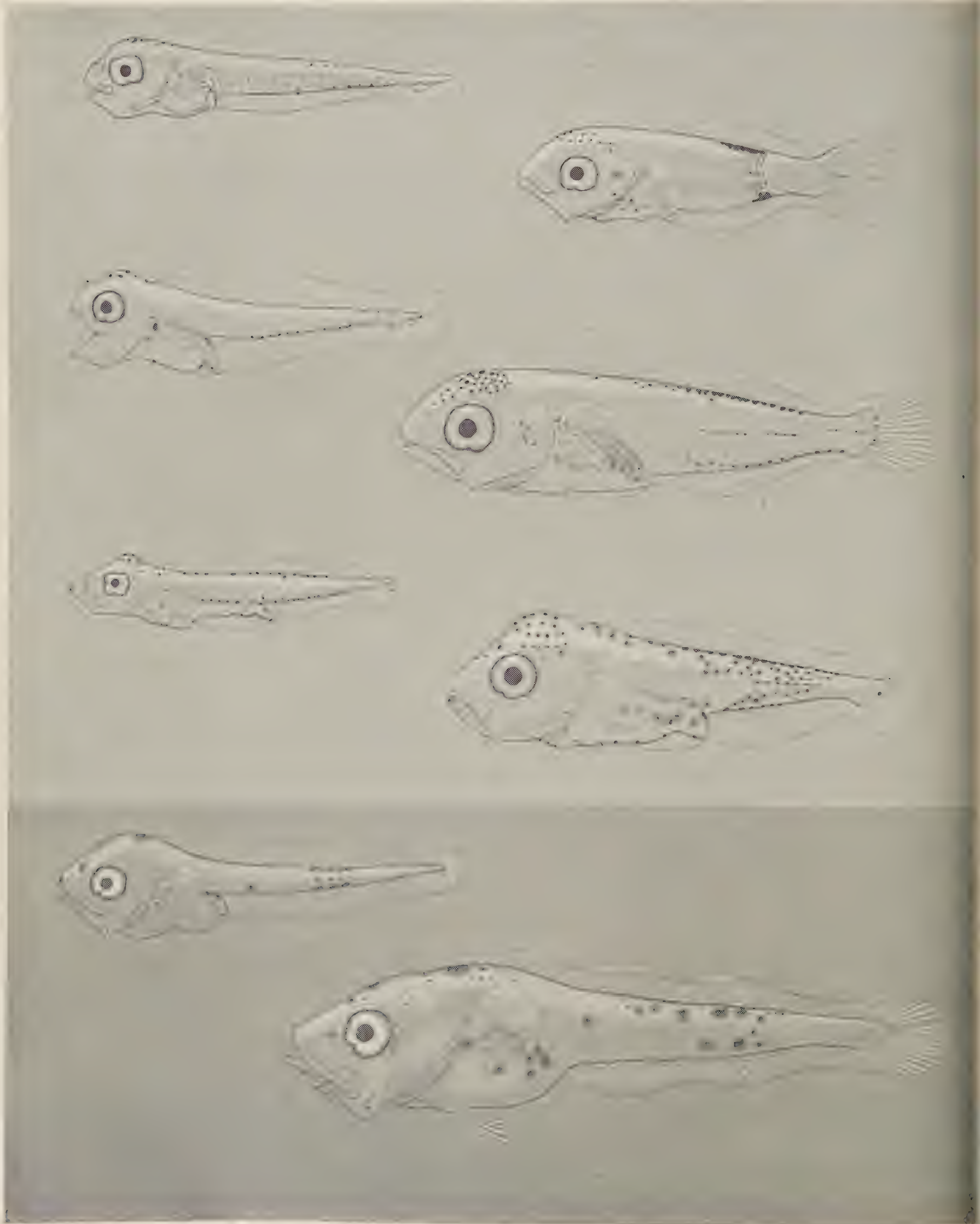

FIGURE 3 From top to bottom—*Chromis punctipinnis* 4.25mm-5.5mm, *Pneumatophorus diego* 4.0mm-7.8mm; *Trachurus symmetricus* 3.5mm–7.4mm and *Merluccius productus* 4.3mm–10.11mm.

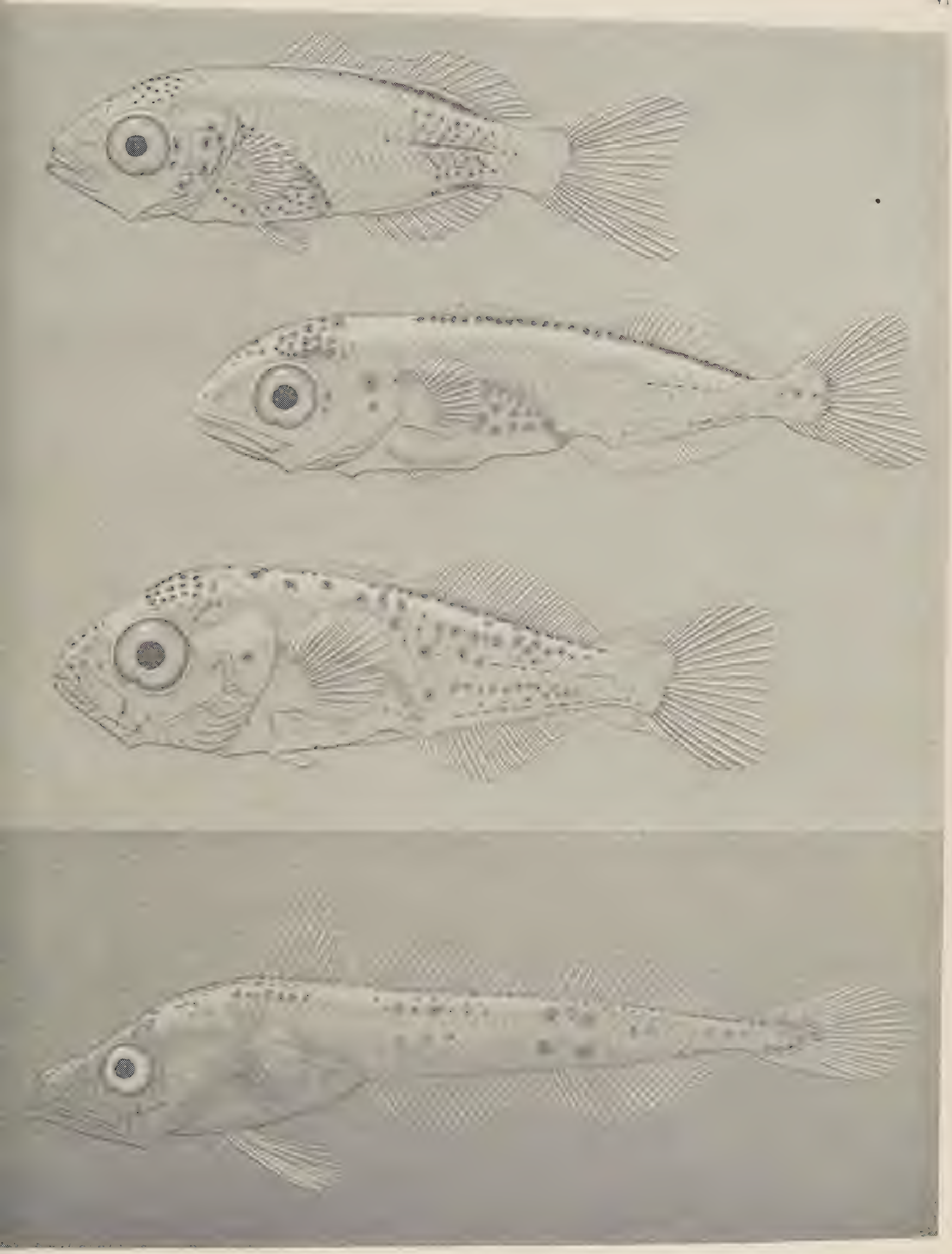

FIGURE 4. From top to bottom—*Chromis punctipinnis* 8.5mm; *Pneumatophorus diego* 10.1mm; *Trachurus symmetricus* 10.0mm and *Merluccius productus* 20.0mm.

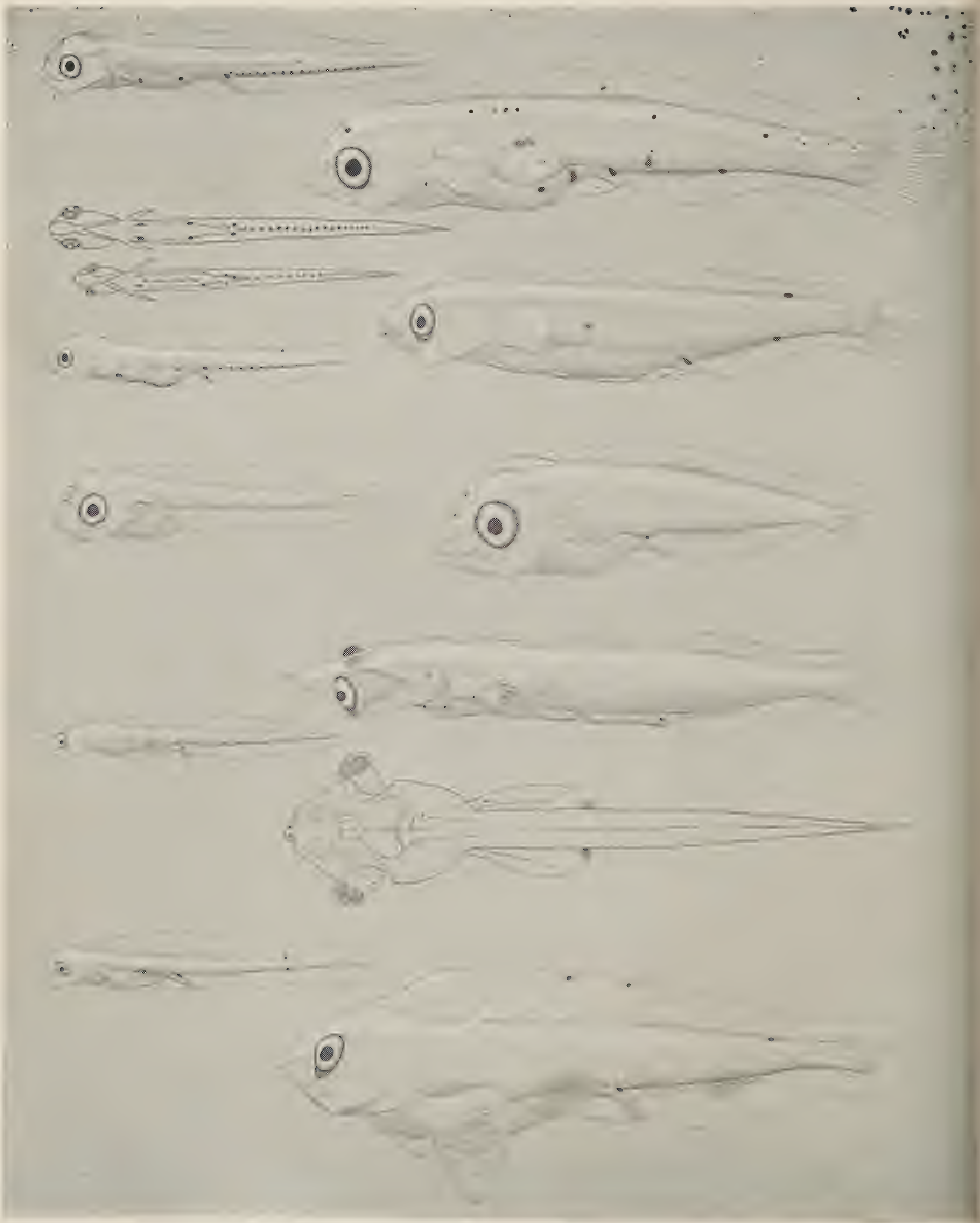

FIGURE 5. From top to bottom—*Lampanyctus leucopsarus* 5.3mm–7.8mm; *Lampanyctus mexicanus* 4.4mm–6.75mm; *Lampanyctus ritteri* 4.3mm–5.75mm; *Symbolophorus californiense* 4.0mm–8.0mm and *Tarletonbeania crenularis* 4.2mm–7.8mm.

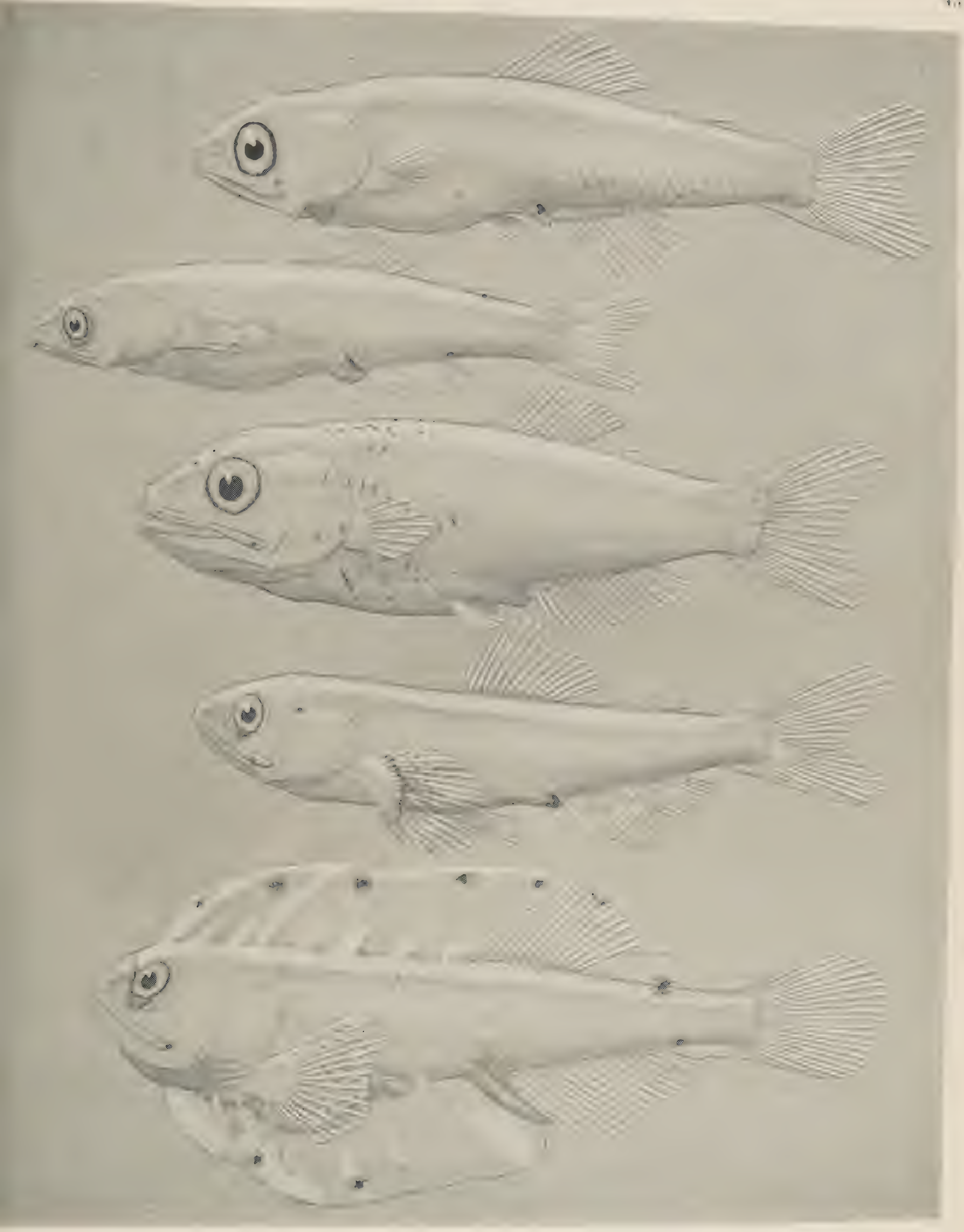

FIGURE 6. From top to bottom—*Lampanyctus leucopsarus* 12.5mm; *Lampanyctus mexicanus* 10.5mm; *Lampanyctus ritteri* 12.5mm; *Symbolophorus californiense* 23.0mm and *Tarletonbeania crenularis* 17.8mm.

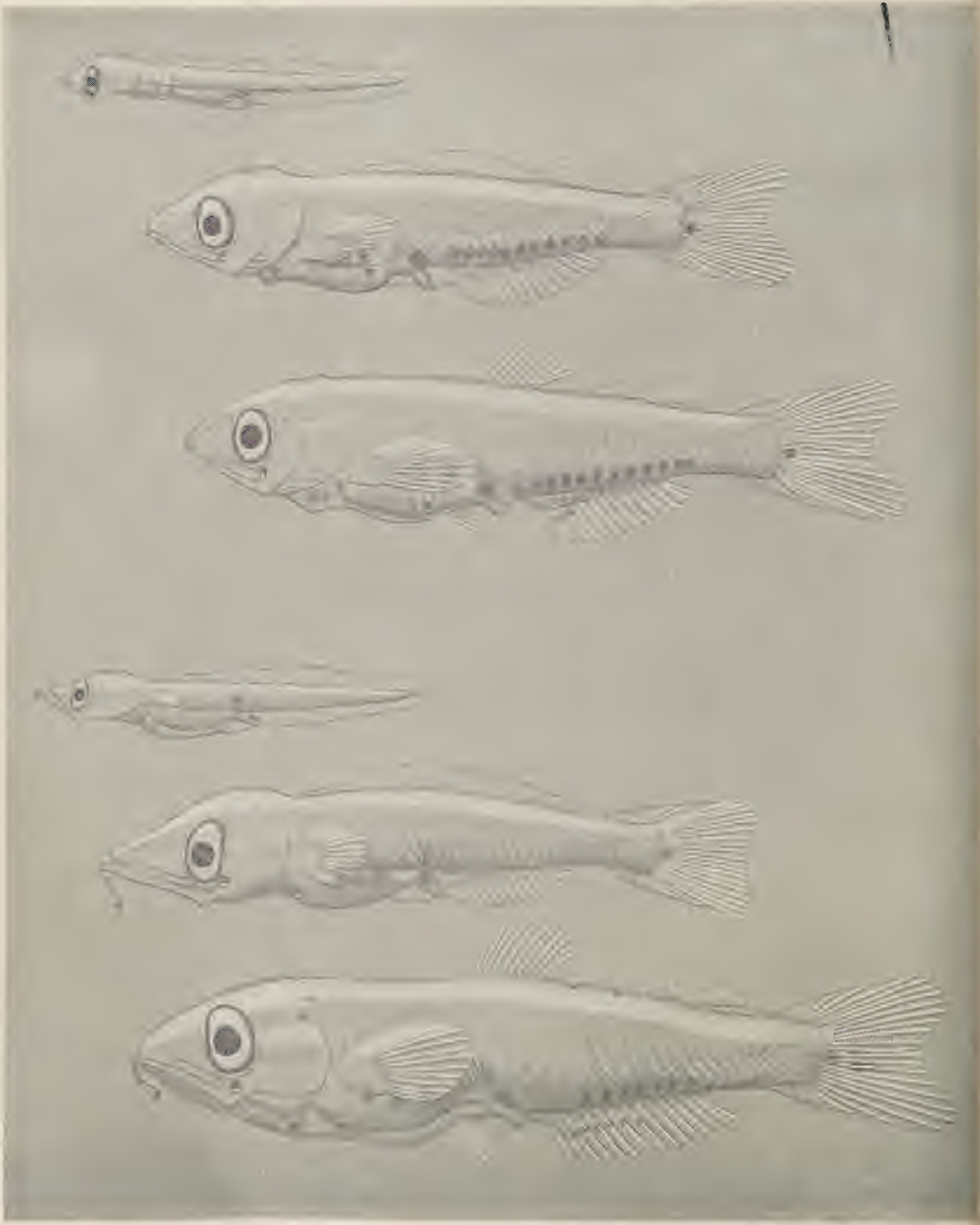

FIGURE 7. From top to bottom—*Diogenichthys laternatus* 3.7mm–7.0mm–9.75mm and *Diogenichthys atlanticus* 4.0mm–6.0mm–11.25mm.

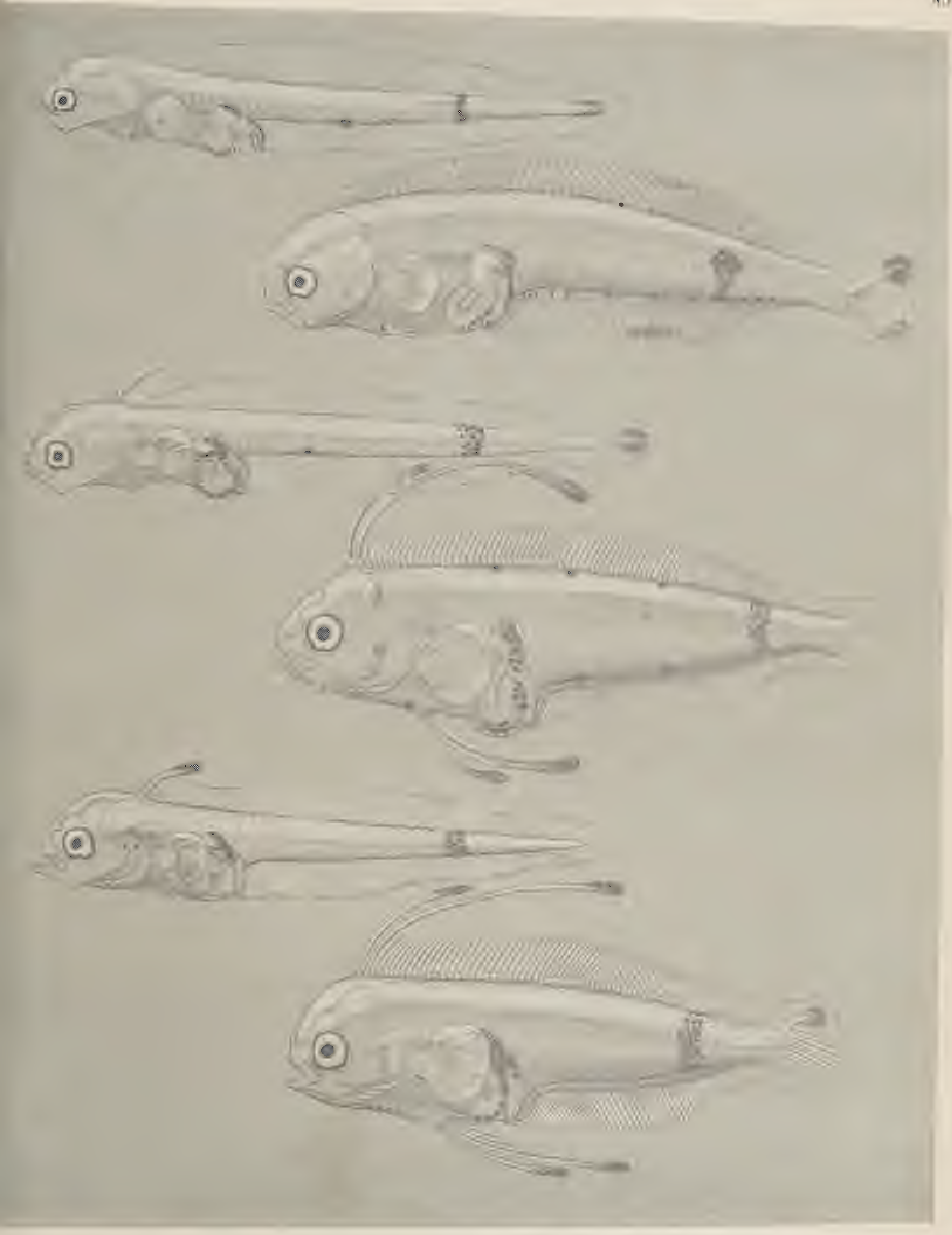

FIGURE 8. From top to bottom—*Citharichthys stigmaeus* 6.5mm–10mm; *Citharichthys sordidus* 6.9mm–10mm and *Citharichthys xanthostigma* 6.2mm–9mm.

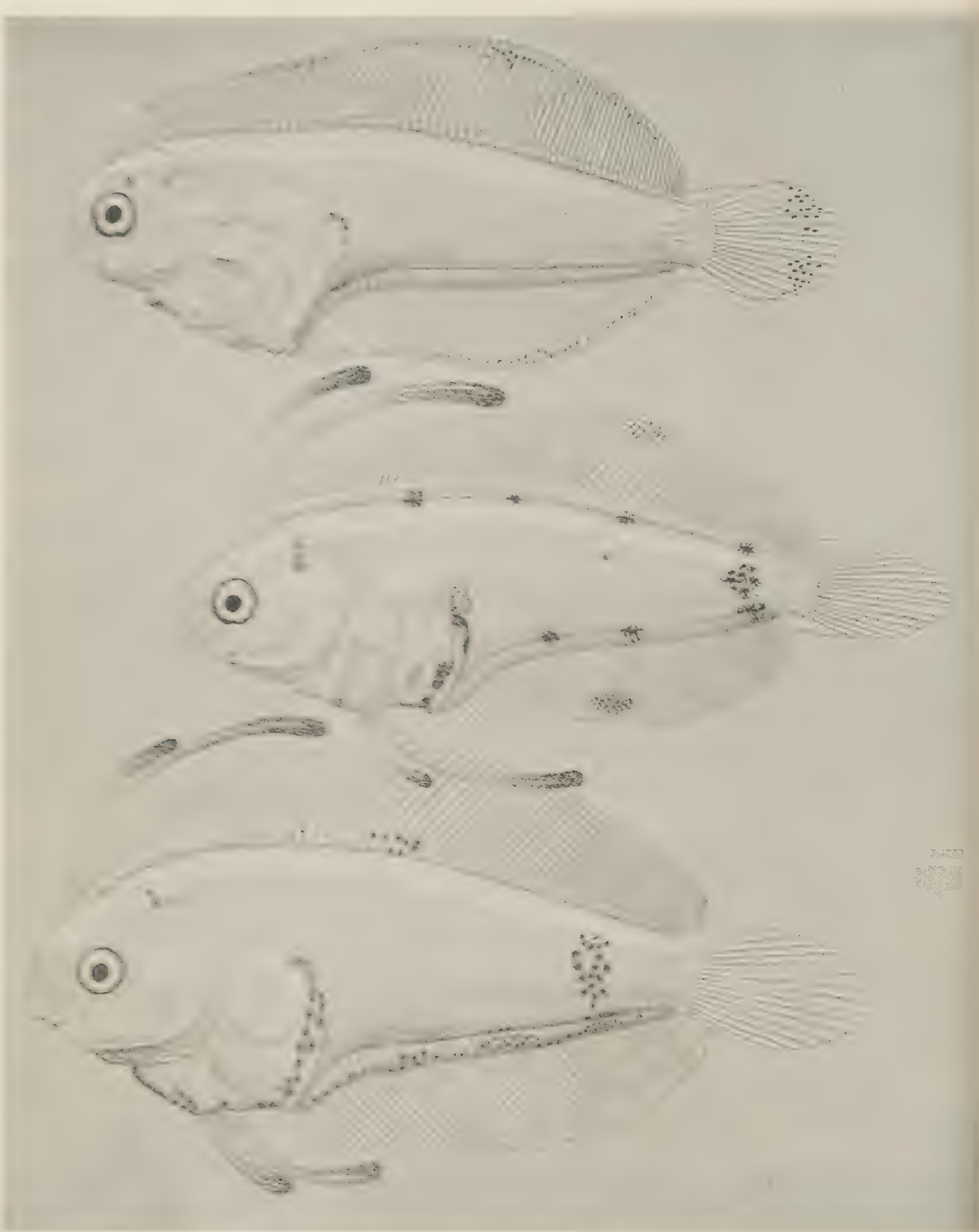

FIGURE 9. From top to bottom—*Citharichthys stigmaeus* 14.75mm; *Citharichthys sordidus* 14.5mm; and *Citharichthys xanthostigma* 15.3mm.

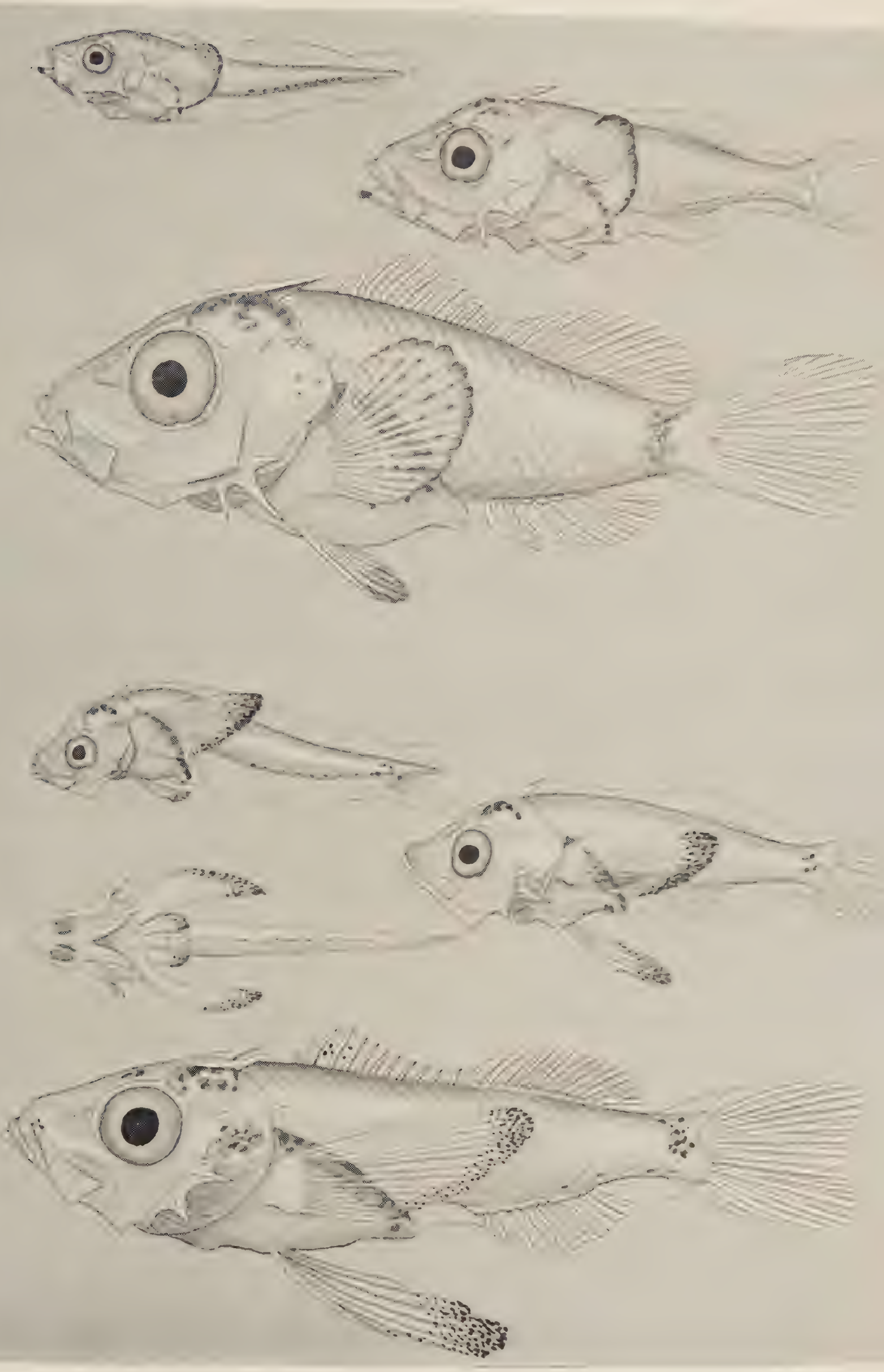

FIGURE 10. From top to bottom—Sebastodes species 6.0mm, 7.8mm, 12.7mm, 6.8, 8.0mm , 6.8mm, and 11.9mm.

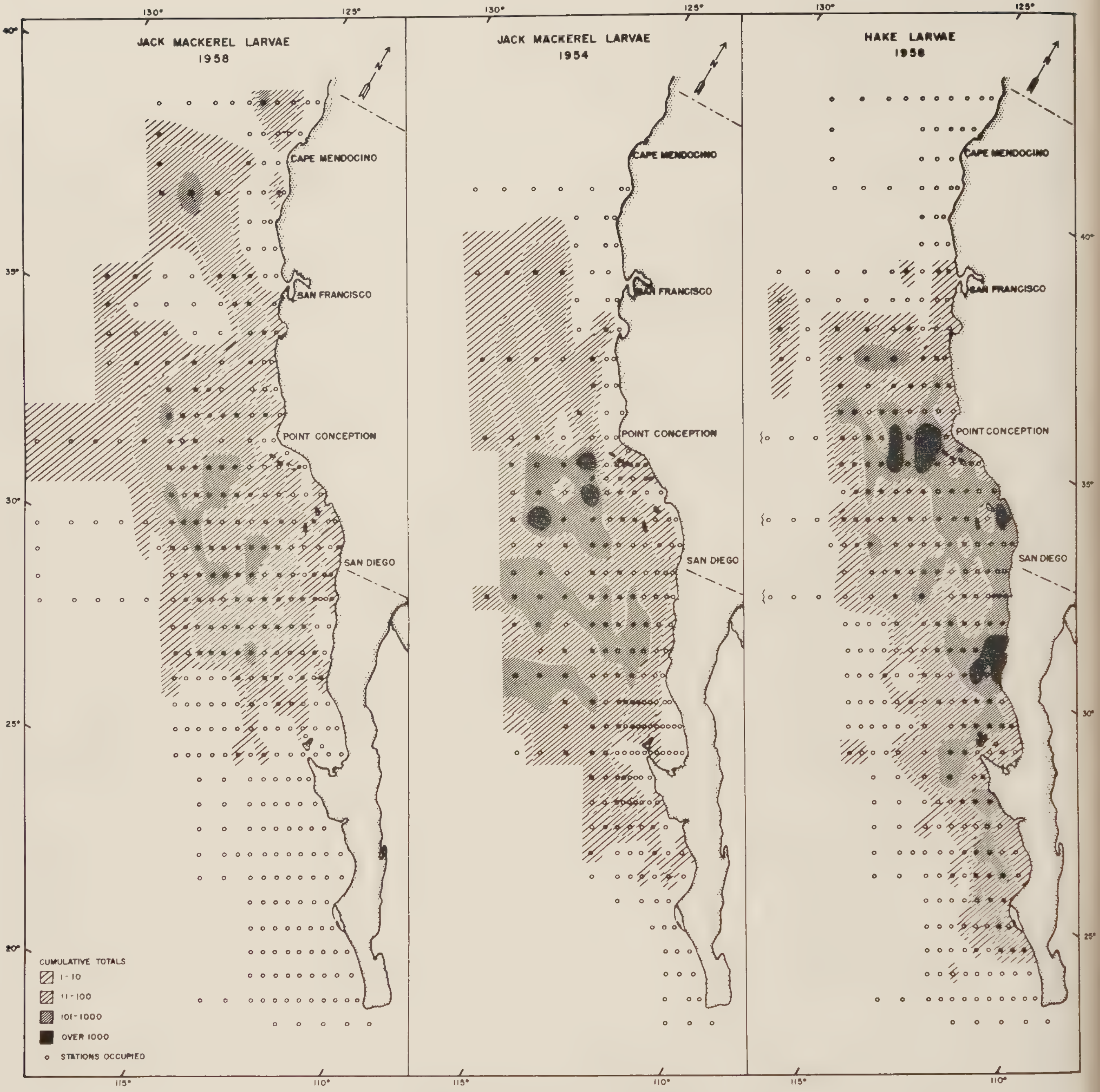
JACK MACKEREL LARVAE
1958
JACK MACKEREL LARVAE
1954
HAKE LARVAE
1958
CAPE MENDOCINO
SAN FRANCISCO
POINT CONCEPTION
SAN DIEGO
N
130°
125°
115°
110°
40°
35°
30°
25°
20°
CUMULATIVE TOTALS
1-10
11-100
101-1000
OVER 1000
STATIONS OCCUPIED

FIGURE 11. Distribution and relative abundance of Jack mackerel larvae, A: 1958; B: 1954; C: Hake larvae, 1958.

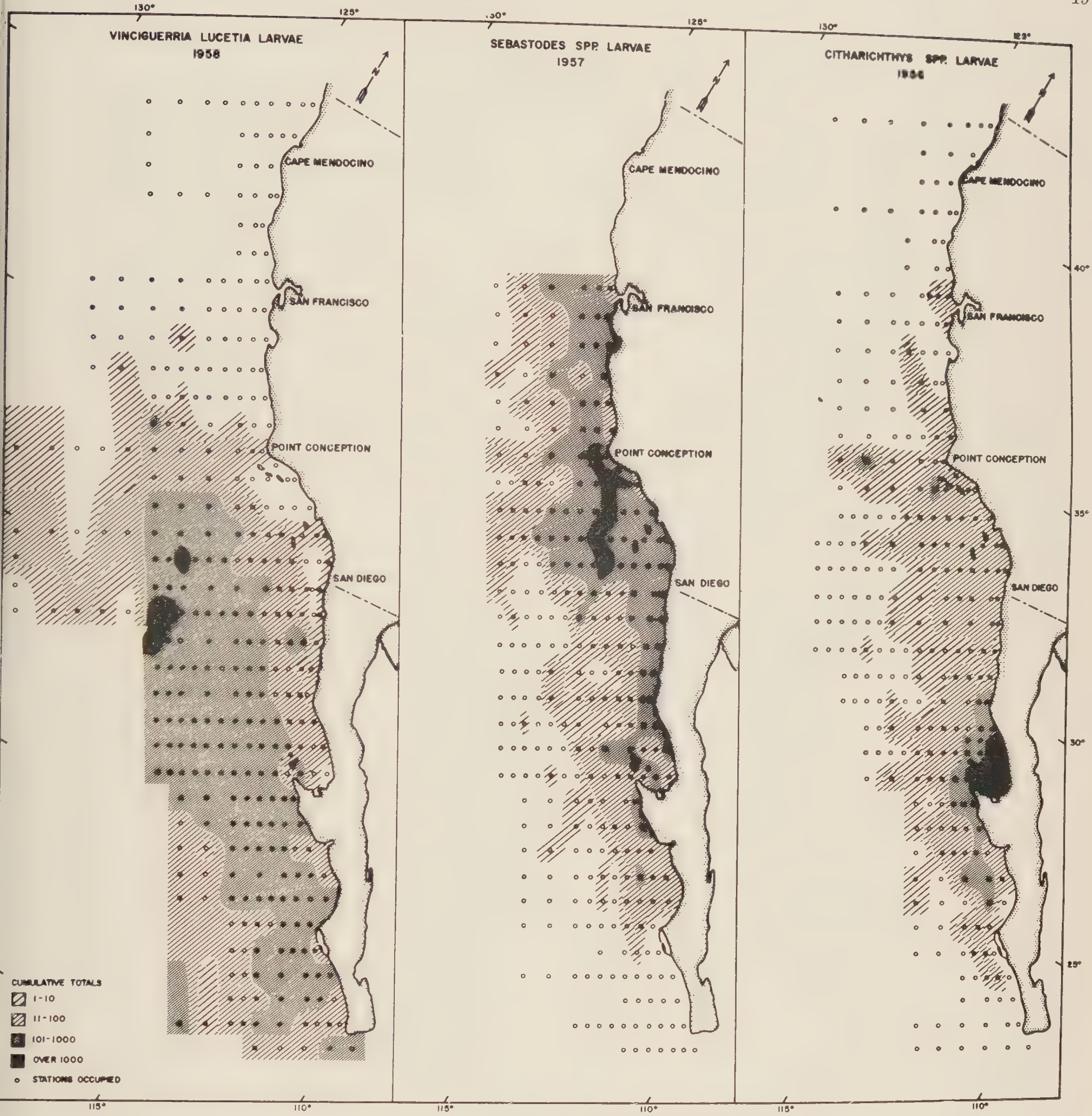
VINCIGUERRIA LUCETIA LARVAE
1958
SEBASTODES SPP. LARVAE
1957
CITHARICHTHYS SPP. LARVAE
1956
CAPE MENDOCINO
SAN FRANCISCO
POINT CONCEPTION
SAN DIEGO
130°
125°
115°
110°
40°
35°
30°
25°
CUMULATIVE TOTALS
1-10
11-100
101-1000
OVER 1000
STATIONS OCCUPIED

FIGURE 12. Distribution and relative abundance of *Vinciguerria lucetia* larvae, A: 1958; B: *Sebastodes* spp. larvae, 1957; C: *Citharichthys* spp. larvae, 1956.

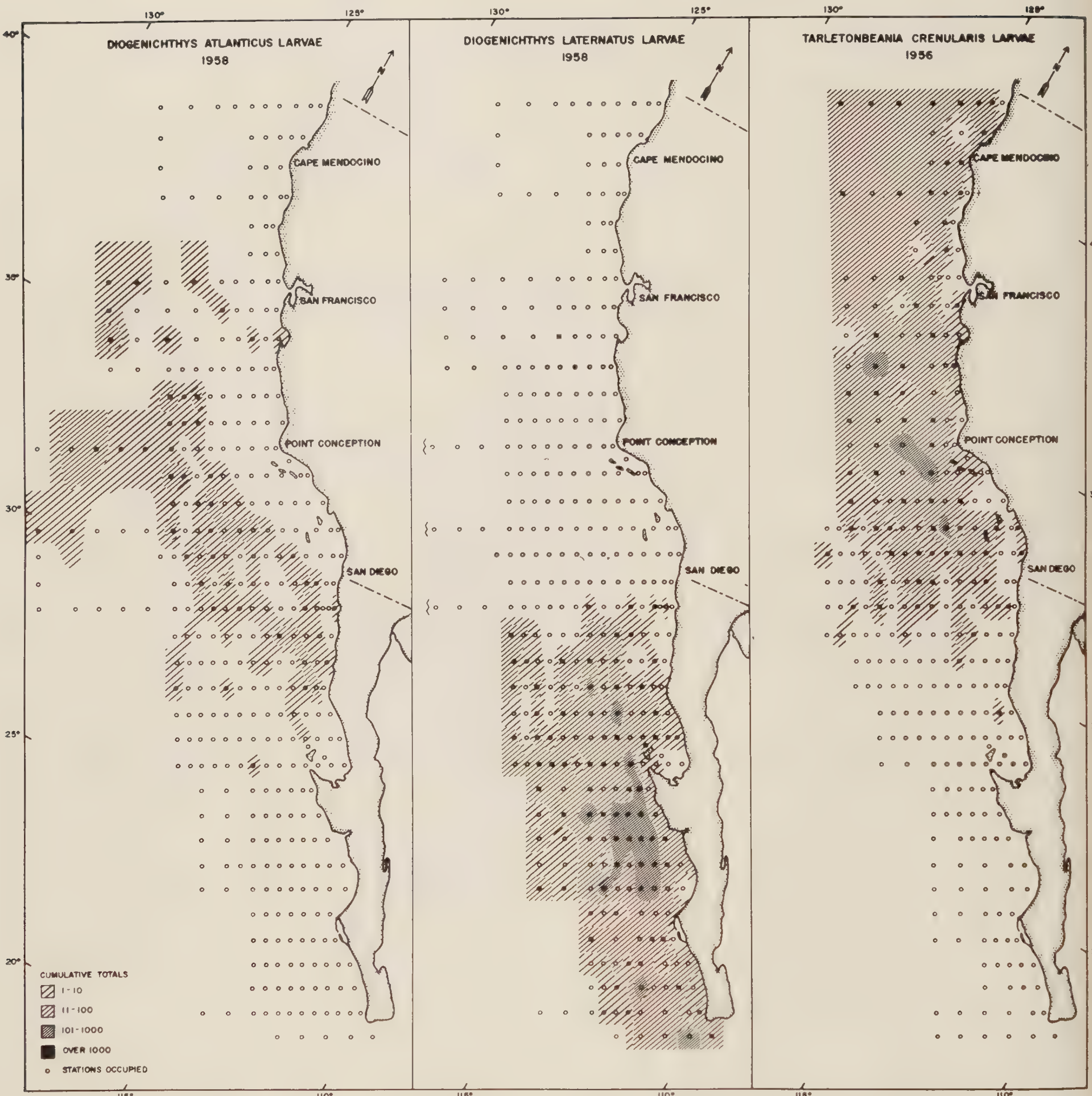
DIOGENICHTHYS ATLANTICUS LARVAE
1958
DIOGENICHTHYS LATERNATUS LARVAE
1958
TARLETONBEANIA CRENULARIS LARVAE
1956
CAPE MENDOCINO
SAN FRANCISCO
POINT CONCEPTION
SAN DIEGO
130°
125°
115°
110°
40°
35°
30°
25°
20°
CUMULATIVE TOTALS
1-10
11-100
101-1000
OVER 1000
STATIONS OCCUPIED

FIGURE 13. Distribution and relative abundance of *Diogenichthys atlanticus* larvae, A: 1958; *Diogenichthys laternatus larvae*, 1958; C: *Tarletonbeania crenularis* larvae, 1956.

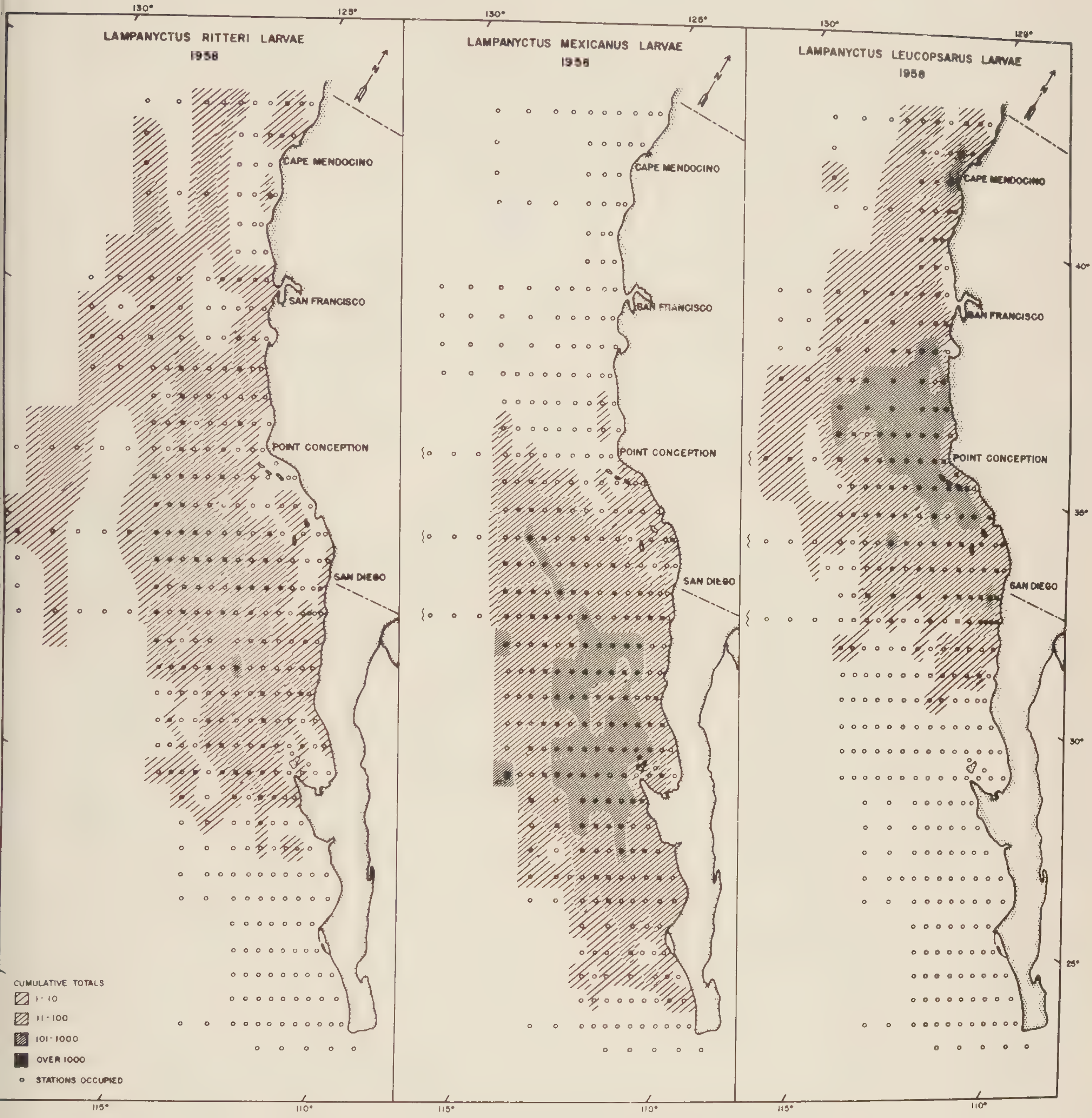
LAMPANYCTUS RITTERI LARVAE
1958
LAMPANYCTUS MEXICANUS LARVAE
1958
LAMPANYCTUS LEUCOPSARUS LARVAE
1958
CAPE MENDOCINO
SAN FRANCISCO
POINT CONCEPTION
SAN DIEGO
130°
125°
40°
35°
30°
25°
115°
110°
N
CUMULATIVE TOTALS
1 - 10
11 - 100
101 - 1000
OVER 1000
STATIONS OCCUPIED

FIGURE 14. Distribution and relative abundance of *Lampanyctus ritteri* larvae, A: 1958; B: *Lampanyctus mexicanus* larvae, 1958; C: *Lampanyctus leucopsarus* larvae, 1958.

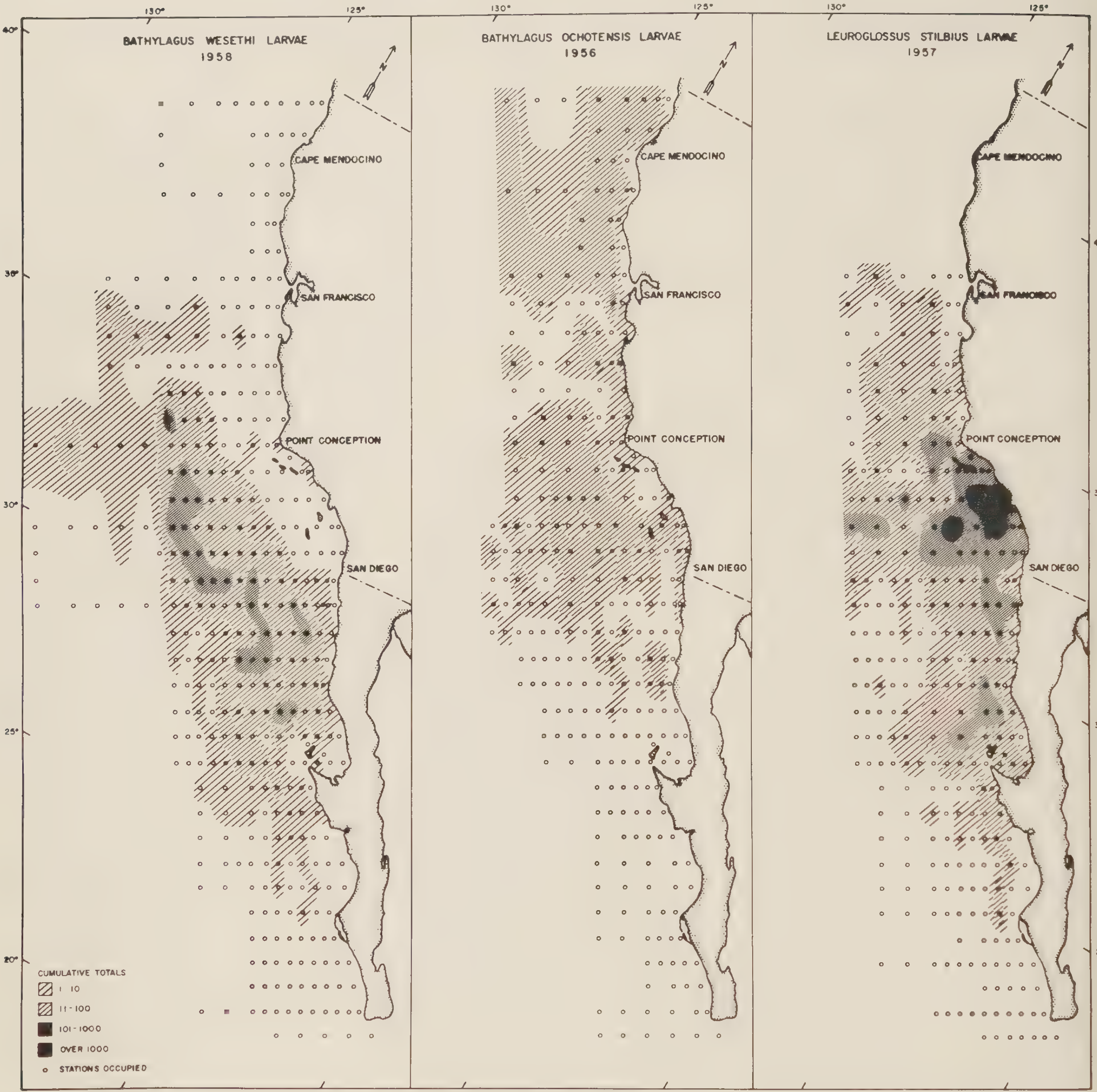
BATHYLAGUS WESETHI LARVAE
1958
BATHYLAGUS OCHOTENSIS LARVAE
1956
LEUROGLOSSUS STILBIUS LARVAE
1957
CAPE MENDOCINO
SAN FRANCISCO
POINT CONCEPTION
SAN DIEGO
N
130°
125°
115°
110°
40°
35°
30°
25°
20°
CUMULATIVE TOTALS
1 - 10
11 - 100
101 - 1000
OVER 1000
STATIONS OCCUPIED

FIGURE 15. Distribution and relative abundance of *Bathylagus wesethi* larvae, A: 1958; B: *Bathylagus ochotensis* larvae, 1956; C: *Leuroglossus stilbius* larvae, 1957.

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# OBSERVATIONS ON THE ECOLOGY AND LIFE CYCLE OF *PROCHRISTIANELLA PENAEI* KRUSE (CESTODA: TRYPANORHYNCHA)

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# OBSERVATIONS ON THE ECOLOGY AND LIFE CYCLE OF *PROCHRISTIANELLA PENAEI* KRUSE (CESTODA: TRYPANORHYNCHA)*

**David V. Aldrich**
U. S. Bureau of Commercial Fisheries Biological Laboratory, Galveston, Texas

ABSTRACT: Examinations of *Penaeus aztecus* and *P. setiferus* from the Galveston Bay area show *Prochristianella penaei* plerocerci to be common in these shrimp, thus extending the known range of this tapeworm to the western Gulf of Mexico. Two years of repeated sampling of shrimp from Clear Lake, a secondary bay in the Galveston Bay system, showed patterns of infection which provided useful leads both to the ecological area where infection of shrimp occurs and the identity of the parasite's definitive host. The relationship found between shrimp size and incidence of infection, when considered with the known migratory habits of *Penaeus aztecus* and *P. setiferus*, suggests that these decapods are uninfected when they enter the bay and are usually infected by the time they leave. Since this pattern showed a rather brackish bay (1‰ to 10‰) to be a probable site in which infection of shrimp takes place, it was assumed that (1) the first intermediate host of *Prochristianella penaei* also inhabits such areas and (2) the range of the elasmobranch final host includes low salinity areas, permitting completion of this cestode's life cycle. The latter point postulates a broad salinity tolerance range for the final host. Discovery of the adult tapeworm in *Dasyatis sabina*, a ray noted for the extent of its salinity tolerance, lends support to these assumptions.

Despite our long acquaintance with penaeid shrimp (e.g., Linnaeus provided the first description of the white shrimp, *Penaeus setiferus*), and the continually increasing commercial importance of these animals during the last 40 years, thorough examinations of shrimp for parasites have not been reported prior to the Florida studies of Hutton et al. and Kruse, both in 1959. As a result, our present knowledge of the ecology and life cycles of shrimp parasites is slight. This situation is particularly true in the western Gulf of Mexico, one of the most productive shrimp habitats in the world.

In 1959, Dr. Edward Chin brought to me for identification a small, white cyst in the digestive gland of a shrimp collected from Galveston Bay. The cyst proved to be the plerocercus stage of a trypanorhynch cestode identical to that described by Kruse (1959) as *Prochristianella penaei*. Since no information is available on the incidence of this parasite except in Florida waters, a survey was undertaken to determine the frequency with which the worm occurred in shrimp from the Galveston area. In addition, the dearth of information on trypanorhynch life cycles coupled with the need for a better understanding of shrimp ecology suggested a search for the undescribed stages in the life history of *P. penaei*. The results of the survey work showed seasonal patterns of infection which proved useful in ascertaining both the ecological area where infection of shrimp occurs and the identity of the parasite's definitive host.

## MATERIALS AND METHODS

In selecting possible sites for regular sampling stations, consideration was given to the fact that both *Penaeus aztecus*, the brown shrimp, and *P. setiferus*, the white shrimp, are migratory in habit. The available life cycle information on these locally abundant species (Viosca, 1920; Weymouth, Lindner, and Anderson, 1933; and Burkenroad, 1934, 1939) indicates that spawning and larval development occur only offshore, the resulting postlarvae (about 0.5 inch in length) moving shoreward to bays, where they spend several months of rapid growth to subadult size (3 to 5 inches long) before migrating offshore again to attain adulthood and spawn. Thus, bays appear to provide important pasture areas for these animals prior to their return to the open waters of the Gulf of Mexico where they were spawned.

Since Clear Lake, a secondary bay in the Galveston Bay complex (Fig. 1), was being sampled for shrimp fairly regularly by other workers at this laboratory, and had been shown to harbor an abundance of both *P. aztecus* and *P. setiferus* (Chin, 1961), it was selected as an area for regular sampling. Monthly mean bottom temperatures for Clear Lake range from 10 to 30 C, and bottom salinity is usually between 1‰ and 10‰.

Offatts Bayou, another secondary bay in the Galveston Bay system, has a comparable temperature regime but a higher salinity range (15‰

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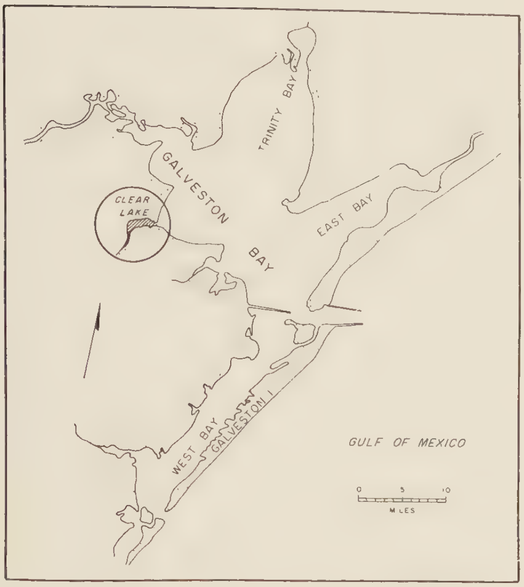

FIGURE 1. Map of Galveston Bay area.

to 29‰). Since this area was also being sampled with some regularity, it was included for comparison with Clear Lake in regard to incidence and intensity of shrimp infection with *Prochristianella penaei.*

The Galveston Bay shrimp were collected with a 10-ft otter trawl (1-inch, stretched-mesh size) towed at 4 to 6 knots for 5 min by outboard motorboat. The offshore samples were taken by the usual commercial method, which employs 40-ft otter trawls. When shrimp catches by either method exceeded 50 animals, approximately 50 shrimp were subsampled from the total catch. As a result, the numbers of shrimp examined could not be considered indices of abundance except when the total (*Penaeus aztecus* plus *P. setiferus*) was less than 48.

When time did not permit their examination on the day of collection, shrimp were stored in a refrigerator at 2 to 4 C for a day or two. The cestodes remained alive under this treatment. For examination, the digestive gland was carefully removed to a large petri dish and thoroughly broken up by repeatedly squirting the tissue out of a medicine dropper. This procedure readily comminutes the follicular tissue of the gland, freeing any helminths present. That region of the shrimp's body cavity which had been occupied by the hepatopancreas was also thoroughly flushed with jets of saline solution from a medicine dropper. All cystlike bodies yielded by this treatment were removed to smaller dishes of saline and cestode plerocerci were identified and counted under a dissecting microscope at 13 and 54 ×. These larvae were fixed with AFA or Bouin's fluid. Final identification was made on picro-carmine stained and cleared specimens. Tentacular armature was examined by phase contrast microscopy at 500 and 1,200 ×, and compared with that figured by Kruse (1959) in his description of *Prochristianella penaei.*

Elasmobranchs were examined within an hour after death. In each case, the spiral valve was removed and opened under saline solution in a large petri dish. Worms were removed either by flushing with saline or pulling gently with a probe inserted between the scolex and intestinal mucosa. Adult worms were fixed in AFA, stained with picro-carmine, and mounted in balsam.

## RESULTS

The overall incidence data show *Prochristianella penaei* to be a common parasite in shrimp of the Galveston area. Of the total 2,097 shrimp examined, 1,006, or 48%, contained this cestode, the infection being quite common in each of the sampling years (Table I). Both of the two most abundant species of shrimp were found to be infected. Overall, 45% of the brown shrimp, *Penaeus aztecus,* and 50% of the white shrimp, *P. setiferus,* contained the tapeworm. Furthermore, infected shrimp were found offshore as well as in various parts of the Galveston Bay complex, suggesting that the worm is widely distributed throughout this area.

The Offatts Bayou shrimp samples revealed a very low and spotty availability of both *P. aztecus* and *P. setiferus,* paralleling the findings of Inglis (1963). As a result, the infection data for this bay are categorized only as to host species and year (Table I). On the other hand, shrimp were found in Clear Lake on every sampling trip during a period extending from April or May through November. Each year, the Clear Lake samples indicated the presence of brown shrimp before white shrimp, the former appearing in April or May, the latter arriving in June (Fig. 2). It has been noted that this sequence of events characterizes not only Galveston Bay in general (Leary and Compton, 1961) but specifically Clear Lake (Chin, 1961). As indicated in Figure 2, *Prochristianella penaei* was present in Clear Lake shrimp throughout most of the period of shrimp abundance.

The incidence of infection in Clear Lake shrimp of 1960 and 1961 was found to increase with the size of shrimp (Fig. 3). In 1960, the rates of increase in infection incidence for *P. aztecus* and *P. setiferus* were comparable, the maximum level of about 80% being reached

TABLE I. *Infection of brown and white shrimp with* Prochristianella penaei *in the Galveston Bay area.*

| Year | Area | *Penaeus aztecus* | | | | | *Penaeus setiferus* | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Size range carapace length (mm) | Number shrimp examined | Number shrimp infected | Per cent incidence | Worms per shrimp (no. and range) | Size range carapace length (mm) | Number shrimp examined | Number shrimp infected | Per cent incidence | Worms per shrimp (no. and range) |
| 1959 | 10–30 miles offshore | 25–47 | 99 | 33 | 33 | 1.5<br>(0–17) | 24–32 | 50 | 35 | 70 | 1.9<br>(0–8) |
| | Miscellaneous parts of Galveston Bay | 16–34 | 21 | 13 | 62 | 1.9<br>(0–14) | 13–39 | 105 | 92 | 88 | 5.5<br>(0–29) |
| | Clear Lake | 10–22 | 101 | 13 | 13 | 0.1<br>(0–2) | 7–23 | 100 | 28 | 28 | 0.6<br>(0–8) |
| 1960 | Miscellaneous parts of Galveston Bay | 8–17 | 90 | 35 | 39 | 0.6<br>(0–5) | – | – | – | – | – |
| | Clear Lake | 8–20 | 104 | 54 | 52 | 2.8<br>(0–18) | 6–24 | 267 | 133 | 50 | 1.5<br>(0–16) |
| | Offatts Bayou | 20–24 | 2 | 1 | – | – | 7–30 | 105 | 39 | 37 | 1.2<br>(0–40) |
| 1961 | Miscellaneous parts of Galveston Bay | – | – | – | – | – | 23–31 | 7 | 7 | 100 | 8.4<br>(4–16) |
| | Clear Lake | 2–25 | 230 | 120 | 52 | 4.3<br>(0–32) | 7–29 | 441 | 189 | 43 | 1.5<br>(0–29) |
| | Offatts Bayou | 5–30 | 173 | 99 | 57 | 2.2<br>(0–26) | 4–31 | 202 | 115 | 57 | 1.7<br>(0–12) |

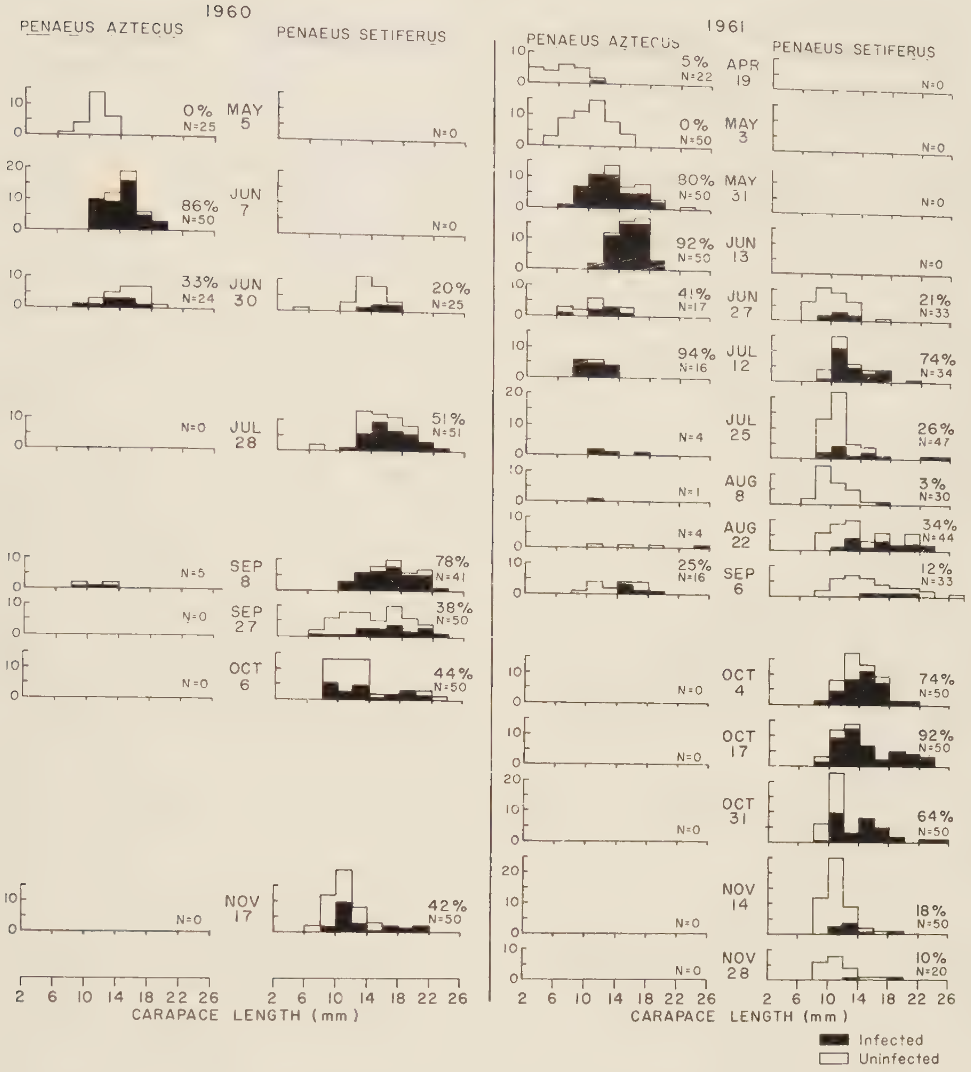

FIGURE 2. Seasonal incidence of shrimp and *Prochristianella penaei* plerocerci in Clear Lake.

in shrimp averaging 20 to 21 mm carapace length. In 1961, on the other hand, *P. aztecus* of about 9 to 14 mm carapace length were more frequently infected than *P. setiferus* of comparable size. Above 14 mm, the incidence of infection leveled off at 70 to 75% for both species.

In both 1960 and 1961, the relationship of shrimp size to intensity of infection (or number of worms per host) showed striking differences between the two species of shrimp (Fig. 4). At smaller size ranges, *P. aztecus* showed a very rapid increase in intensity of infection with increasing size. However, above 13 to 15 mm carapace length, the number of worms per shrimp failed to increase further. In both years, brown shrimp showed the more rapid increase in intensity of infection and were generally more heavily parasitized than white shrimp of comparable size. White shrimp also showed increasing intensity of infection with increasing size of host in both years. In 1960, this relationship continued throughout the size range, but in 1961 a peak was reached at about 18 mm carapace length, and white shrimp larger than this contained fewer worms. The

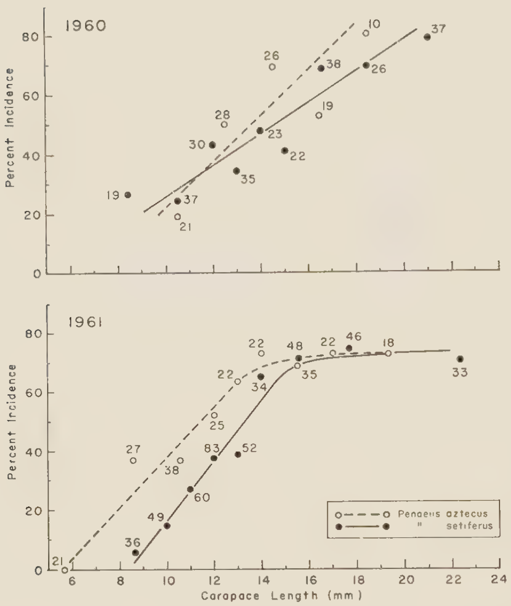

FIGURE 3. Incidence of *Prochristianella penaei* in shrimp of various sizes from Clear Lake. The number of shrimp represented by each point is indicated by the number adjacent to it.

1959 shrimp samples from Clear Lake were too few and scattered to demonstrate reliable patterns.

## DISCUSSION

The present results clearly establish *Prochristianella penaei* as a common parasite of both species of commercially important shrimp in the Galveston area. This fact extends the known range of this tapeworm to the northwestern Gulf of Mexico. Although *P. penaei* was first described by Kruse (1959) from three species of penaeid shrimp in Florida, this worm was probably first discussed by Woodburn et al. (1957), who found "a larval trypanorhynchan cestode" in the hepatopancreas area of penaeid shrimp all along the west coast of Florida as well as near the Tortugas. Hutton et al. (1959) confirmed this distribution and further identified the worm as *Prochristianella* sp.

It is possible that the larval trypanorhynch cestode noted by Sparks and Mackin (1957) in *Penaeus setiferus* from Barataria Bay, Louisiana is *Prochristianella penaei*. However, it is not possible to confirm this point on the basis of their published account.

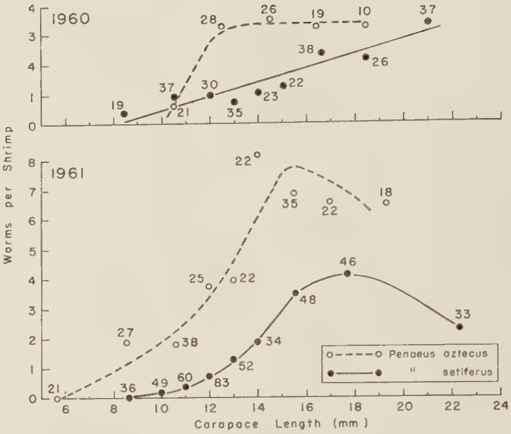

FIGURE 4. Intensity of *Prochristianella penaei* infection in shrimp of various sizes from Clear Lake. The number of shrimp represented by each point is indicated by the number adjacent to it.

In regard to the relative incidence of this parasite in penaeid shrimp of the Gulf of Mexico, it should be noted that Hutton et al. (1959) found *P. penaei* plerocerci in 63% of 295 *Penaeus duorarum* taken from various locations on the Florida west coast and concluded: "The larva of *Prochristianella* sp. has been found in shrimp from all areas and thus far does not appear to be of value in migration studies." Sampling in three locations within the northernmost portion of the Florida west coast, Kruse (1959) found 94% of 301 shrimp (including *Penaeus setiferus*, *P. aztecus*, and *P. duorarum*) to be infected, with each species having over 90% incidence. The striking variability between biweekly samples shown in the present work suggests that more intensive sampling during comparable seasonal periods will be necessary to compare the incidence of this cestode in shrimp from different areas. Adequate incidence data for various bays and offshore areas of the Gulf of Mexico would be of considerable interest in determining the potential utility of *Prochristianella penaei* as a biological shrimp "tag."

The data indicate a relationship between size of Clear Lake shrimp and incidence of infection with *P. penaei*. Tapeworm incidence increased with size of host in both species of shrimp (Fig. 3). The fact that this pattern exists for the estuarine portion of the shrimp life cycle indicates that shrimp entering Clear Lake tend to be much more lightly infected with *P. penaei* than those leaving the bay to begin their offshore movement. These results indicate that shrimp frequently acquire the infection within Clear Lake.

The ecological implications of these findings were considered in seeking the final host of this cestode. If the infection of shrimp occurs in the low salinity waters of Clear Lake, it is reasonable to assume that the shark or ray harboring the adult worm is a common inhabitant of brackish water (in which infection of the first intermediate host must occur). *Dasyatis sabina*, the commonest sting ray in Texas bays seems to satisfy this requirement. Discussing this ray, Bigelow and Schroeder (1953) noted: "The salinity of the water influences its distribution but little if at all, for it occurs throughout the entire range from fresh water up to full oceanic salinity. . . ." Several specimens of *D. sabina* from Galveston Bay were examined and found to contain adult *Prochristianella penaei* in the spiral valve. Although the first worm specimens, taken in May 1960, had scarcely developed beyond the scolex, they were completely excysted from the blastocyst and actively attaching to the spiral valve mucosa. Specimens collected in August 1963 showed more complete development, including mature segments. Identifications were made on the basis of several critical characters of tentacular structure and armature, following Dollfus (1946) and Kruse (1959): (1) presence of basal tentacular swelling with typical hook pattern; (2) presence of a longitudinal row of very large hooks on the internal metabasal tentacular surface; and (3) smaller hooks arranged in rows, and diminishing in size along the rows which extend from the internal to the external tentacular surface. Kruse (personal communication) has confirmed my identification of the adult worm and informed me that he has independently found adults in *D. sabina* since his earlier work (1959), which showed several specimens of that ray to be negative for adult *Prochristianella penaei*. Observations on the food habits of this ray, together with further details of the adult tapeworm's morphology will be published elsewhere.

Since no life cycles have been experimentally completed among the Trypanorhyncha, we can only assume that the observations of Ruszkowski (1932, 1934) and Riser (1956) may be representative of this order of tapeworms. If so, a procercoid stage of *P. penaei* exists, probably in small invertebrate-inhabiting, estuarine waters.

In addition to the obvious parasitological interest in completing this trypanorhynch life cycle, such work may have important applications in shrimp ecology. Due to the effective shredding action of the gastric mill in shrimp, attempts to gain food habit information using routine stomach analysis methods have not produced very useful results. Gut contents consist either of fragments tough enough to withstand the mill action (such as bits of mollusk shell, crustacean exoskeleton, or annelid setae) or of the amorphous material to which softer dietary portions have been reduced. Such substances are very difficult or impossible to identify. As a result, there is very little definitive information on feeding habits of shrimp. It is possible that completion of the life cycle of *P. penaei* will provide valuable information relating to this problem. The rapidity with which this tapeworm is acquired by shrimp after they enter Clear Lake indicates that the previous host may be an important natural food of shrimp.

A number of intriguing questions are posed by the infection data presented above. For example, it is clear that in both 1960 and 1961, *Penaeus aztecus* of a given size almost always contained more worms per shrimp than did *P. setiferus* of the same size (Fig. 4). Are these striking differences between shrimp species in intensity of infection due to (1) variable seasonal availability of infected first intermediate hosts combined with the difference in seasonal abundance of white and brown shrimp in Clear Lake; (2) food habit differences between species of shrimp; or (3) differences in susceptibility to infection between shrimp species? Other questions may be raised concerning the apparent "leveling off" of infection intensity in *P. aztecus* above 14 mm in carapace length. Is this due to change in food habit or increase in immunity? Some of these questions have led to work now in progress which includes the examination of Clear Lake bottom samples for small, procercoid-infected invertebrates, and the holding of shrimp and rays in the laboratory to effect completion of the life cycle of *Prochristianella penaei* under controlled conditions.

## ACKNOWLEDGMENTS

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## LITERATURE CITED

Bigelow, H. B., and W. C. Schroeder. 1953. Fishes of the western North Atlantic. Part II. Sawfishes, guitarfishes, skates, rays, and chimaeroids. Sears Found. Mar. Res., New Haven, 588 p.

Burkenroad, M. D. 1934. The Penaeidea of Louisiana with a discussion of their world relationships. Bull. Am. Mus. Nat. Hist. **68:** 61–143.

———. 1939. Further observations on Penaeidae of the Northern Gulf of Mexico. Bull. Bingham Oceanogr. Coll. **6** (Art. 6): 1–62.

Chin, E. 1961. A trawl study of an estuarine nursery area in Galveston Bay, with particular reference to penaeid shrimp. Ph.D. thesis, Univ. of Washington, Seattle.

Dollfus, R. Ph. 1946. Notes diversés sur des tetrarhynques. Mém. Mus. Hist. Nat., Paris **22:** 179–220.

Hutton, R. F., F. Sogandares-Bernal, B. Eldred, R. M. Ingle, and K. D. Woodburn. 1959. Investigations on the parasites and diseases of saltwater shrimps (Penaeidae) of sports and commercial importance to Florida. Fla. State Bd. Consv., Tech. Ser., No. 26, 38 p.

Inglis, A. 1963. Ecology of nursery areas. U. S. Fish and Wildl. Serv., Circ. 161, p. 47–51.

Kruse, D. N. 1959. Parasites of the commercial shrimps *Penaeus aztecus* Ives, *P. duorarum* Burkenroad, and *P. setiferus* (Linnaeus). Tulane Stud. Zool. **7:** 123–144.

Leary, T., and H. Compton. 1961. A study of the bay populations of juvenile shrimp, *Penaeus aztecus* and *Penaeus setiferus*. *In* Project Reports 1959–1960; Mar. Fish. Div., Tex. Game and Fish Comm., 32 p.

Riser, N. W. 1956. Early larval stages of two cestodes from elasmobranch fishes. Proc. Helm. Soc. Wash. **23:** 120–124.

Ruszkowski, J. S. 1932. Études sur le cycle évolutif et sur la structure des cestodes marins. III. Le cycle évolutif du tétrarhynque *Grillotia erinaceus* (Van Beneden, 1858). Acad. Polon. Sci. et Lett., Compt. Rend. Mens. Cl. Sci. Math. et Nat. **9:** 6.

———. 1934. Études sur le cycle évolutif et sur la structure des cestodes de mer. III. Le cycle évolutif du tétrarhynque *Grillotia erinaceus* (Van Beneden, 1858). Mem. Acad. Polon. Sci. et Lett., Cracovie, Cl. Sci. Math. et Nat., s. B.: Sci Nat. **6:** 1–9.

Sparks, A. K., and J. G. Mackin. 1957. A larval trypanorhynchid cestode from commercial shrimp. Texas J. Sci. **9:** 475–476.

Viosca, P., Jr. 1920. Report of the biologist. La. Dept. Consv., 4th Bienn. Rept. 1918–20, p. 120–130.

Weymouth, F. W., M. J. Lindner, and W. W. Anderson. 1933. Preliminary report on the life history of the common shrimp (*Penaeus setiferus* (Linn.). U. S. Bur. Fish., Bull. **48:** 1–26.

Woodburn, K. D., B. Eldred, E. Clark, R. F. Hutton, and R. M. Ingle. 1957. The live bait shrimp industry of the west coast of Florida (Cedar Key to Naples). Fla. State Bd. Consv., Tech. Ser., No. 21, 33 p.

# NEW ATLANTIC COAST RANGES FOR FISHES

William D. Anderson, Jr., and Elmer J. Gutherz

Specimens of *Corniger spinosus, Holocentrus ascensionis, Myripristis jacobus,* and *Ostichthys trachypomus* (Holocentridae); *Anisotremus virginicus* (Pomadasyidae); *Chaetodon sedentarius* and *Holacanthus tricolor* (Chaetodontidae); and *Bodianus pulchellus* and *Clepticus parrai* (Labridae) have been collected by the U. S. Bureau of Commercial Fisheries exploratory fishing vessels *Combat, Silver Bay,* and *Delaware* at localities along the Atlantic coast of the United States north of their previously reported ranges. These specimens are in the collections of the U. S. Bureau of Commercial Fisheries Biological Laboratory, Brunswick, Georgia, unless otherwise indicated. We are grateful to Loren P. Woods of the Chicago Natural History Museum and Bruce B. Collette of the Bureau of Commercial Fisheries Ichthyological Laboratory, for their comments on the manuscript, and to Robert H. Gibbs, Jr., Division of Fishes, U. S. National Museum, for the loan of specimens.

## 1. *Corniger spinosus* Agassiz

Four specimens (103-122 mm S.L.) from *Silver Bay* stations 1393, 2989, 5507, and 5579. Range previously reported as "costas del Brasil" and Cuba north of Havana by Howell Rivero (1941, pp. 3-7). The collection of the specimen off Cape Romain, S. C. (*Silver Bay* station 1393), represents a range extension of about 650 nautical miles northward from Cuba, along the Atlantic coast of the United States.

## 2. *Holocentrus ascensionis* (Osbeck). Squirrelfish

Twelve specimens (180-276 mm S.L.) from *Silver Bay* stations 1534, 2999, 3000, 3330, 3649, 4672, 5417, 5418, 5419, and 5420; and four specimens (22-40 mm S.L., deposited in the U. S. National Museum) collected by Robert H. Gibbs, Jr. with dip net and night light, while aboard the *Delaware* 38°56′N. Lat., 66°27′W. Long. (USNM 194241), 39°07′N. Lat., 65°58′W. Long. (USNM 194239), 37°02′N. Lat., 71°20′W. Long. (USNM 194240), and 39°44.5′N. Lat., 70°56′W. Long. (USNM 194244). Range previously reported as "Both side of the Atlantic; in the western Atlantic from Ber-

## TABLE 1

Data for *Combat, Silver Bay,* and *Delaware* collections listed in text

| Station | | Position | | Distance and Direction from Nearest Landfall (Approximate Nautical Miles) | Depth (Fathoms) | Date |
|---|---|---|---|---|---|---|
| | | N. Lat. | W. Long. | | | |
| *Combat* 353 | | 30°24′ | 80°20′ | 54 E Jacksonville Beach, Fla. | 24 | 3 June 1957 |
| *Silver Bay* | 1207 | 33°24′ | 77°09′ | 49 ESE Cape Fear, N. C. | 25 | 2 Sept. 1959 |
| do | 1233 | 34°00′ | 76°21′ | 37 S Cape Lookout, N. C. | 30/33 | 5 Sept. 1959 |
| do | 1268 | 34°32′ | 75°53′ | 35 E. Cape Lookout, N. C. | 31/30 | 11 Sept. 1959 |
| do | 1297 | 34°09′ | 76°35′ | 26 S Cape Lookout, N. C. | 20 | 23 Sept. 1959 |
| do | 1393 | 32°32′ | 78°40′ | 45 SE Cape Romain, S. C. | 40/50 | 26 Oct. 1959 |
| do | 1506 | 33°40.5′ | 76°59.5′ | 50 E Cape Fear, N. C. | 21/22 | 9 Dec. 1959 |
| do | 1534 | 30°39′ | 80°17′ | 60 E. Amelia Is., Fla. | 22/23 | 15 Jan. 1960 |
| do | 1734 | 32°51′ | 78°39′ | 35 SE South Is., S. C. | 17 | 7 March 1960 |
| do | 1738 | 33°04′ | 77°59′ | 47 S Cape Fear, N. C. | 20/21 | 7 March 1960 |
| do | 2543 | 33°26′ | 77°13′ | 45 ESE Cape Fear, N. C. | 22 | 6 Dec. 1960 |
| do | 2989 | 30°43′ | 80°07′ | 69 E Amelia Is., Fla. | 26/28 | 18 April 1961 |
| do | 2999 | 30°25′ | 80°25′ | 51 E Talbot Is., Fla. | 19 | 20 April 1961 |
| do | 3000 | 30°29′ | 80°27′ | 49 E Talbot Is., Fla. | 21 | 20 April 1961 |
| do | 3009 | 29°45′ | 80°28′ | 40 E Anastasia Is., Fla. | 18 | 21 April 1961 |
| do | 3010 | 29°45′ | 80°28′ | 40 E Anastasia Is., Fla. | 18 | 21 April 1961 |
| do | 3330 | 33°15.5′ | 77°15.5′ | 34 S Cape Fear, N. C. | 17 | 13 Aug. 1961 |
| do | 3649 | 33°17′ | 77°46′ | 34 S Cape Fear, N. C. | 18 | 11 Dec. 1961 |
| do | 4117 | 34°34′ | 76°13′ | 16 E Cape Lookout, N. C. | Surface | 2 June 1962 |
| do | 4183 | 33°21′ | 77°39′ | 34 SE Cape Fear, N. C. | 14/16 | 28 July 1962 |
| do | 4652 | 33°15.5′ | 77°51.5′ | 35 S Cape Fear, N. C. | 17 | 25 Jan. 1963 |

TABLE 1 (cont.)

Data for *Combat, Silver Bay,* and *Delaware* collections listed in text

| Station | | Position | | Distance and Direction from Nearest Landfall | Depth | Date |
|---|---|---|---|---|---|---|
| | | N. Lat. | W. Long. | (Approximate Nautical Miles) | (Fathoms) | |
| do | 4665 | 32°45′ | 78°33.5′ | 43 ESE Cape Romain, S. C. | 23/20 | 27 Jan. 1963 |
| do | 4672 | 32°45′ | 78°33.5′ | 43 ESE Cape Romain, S. C. | 20/24 | 29 Jan. 1963 |
| do | 4673 | 32°45′ | 78°33.5′ | 43 ESE Cape Romain, S. C. | 20/24 | 29 Jan. 1963 |
| do | 4921 | 30°21.5′ | 80°50.5′ | 29 E Jacksonville Beach, Fla. | 17/18 | 8 May 1963 |
| do | 4938 | 30°45′ | 80°15′ | 62 E Cumberland Is., Ga. | 21.5 | 14 May 1963 |
| do | 5390 | 31°50′ | 79°32.5′ | 53 SE Kiawah Is., S. C. | 35 | 6 Dec. 1963 |
| do | 5391 | 31°49.5′ | 79°34.5′ | 52 SE Kiawah Is., S. C. | 35 | 6 Dec. 1963 |
| do | 5393 | 31°56.5′ | 79°23.5′ | 51 SE Kiawah Is., S. C. | 40/44 | 6 Dec. 1963 |
| do | 5417 | 30°46′ | 80°16′ | 62 E. Cumberland Is., Ga. | 22 | 15 Dec. 1963 |
| do | 5418 | 30°53′ | 80°07′ | 67 E Cumberland Is., Ga. | 21/22 | 16 Dec. 1963 |
| do | 5419 | 30°50′ | 80°10′ | 66 E Cumberland Is., Ga. | 22 | 16 Dec. 1963 |
| do | 5420 | 30°44′ | 80°15′ | 62 E Cumberland Is., Ga. | 21 | 16 Dec. 1963 |
| do | 5437 | 32°58′ | 78°36′ | 33 SE North Island, S. C. | 16 | 16 Jan. 1964 |
| do | 5507 | 29°18.5′ | 80°13′ | 43 E Ormond Beach, Fla. | 40 | 28 Feb. 1964 |
| do | 5516 | 27°58.5′ | 80°15′ | 13 NE Sebastian Inlet, Fla. | 14 | 29 Feb. 1964 |
| do | 5579 | 29°02′ | 80°07.5′ | 40 E New Smyrna Beach, Fla. | 44/50 | 11 March 1964 |
| do | 5682 | 30°03′ | 80°33′ | 39 ENE Anastasia Is., Fla. | 22 | 30 April 1964 |
| *Delaware* | | 38°56′ | 66°27′ | 225 SE Nantucket Is., Mass. | Surface | 8 June 1957 |
| do | | 39°07′ | 65°58′ | 240 SE Nantucket Is., Mass. | Surface | 21 Sept. 1957 |
| do | | 38°05′ | 65°58′ | 270 SE Nantucket Is., Mass. | Surface | 22 Sept. 1957 |
| do | | 37°02′ | 71°20′ | 200 SE Assateague Is., Va. | Surface | 18 July 1958 |
| do | | 39°44.5′ | 70°56′ | 100 SE Montauk Pt., N. Y. | Surface | 27 Aug. 1959 |

muda and Florida to Rio de Janeiro and the northern and western Gulf of Mexico" by Briggs (1958, p. 271). McKenney (1959, p. 208) cited several obscure references in which *Holocentrus* had been reported from as far north as Newport, Rhode Island, and Woods Hole, Massachusetts; these records might have been of pelagic juveniles and might refer to *H. ascensionis.* Gibbs and Collette (1959, pp. 145-146) found four specimens of *H. ascensionis* in the stomach contents of a *Coryphaena hippurus* "from the Gulf Stream." The stomach contents mentioned by Gibbs and Collette were collected from the *Delaware* at 38°58′N. Lat., 66°26′W. Long. on 9 June 1957 (Bruce B. Collette, *in litt.*, 19 August 1964). The collection of the specimen (USNM 194244) from SE of Montauk Pt., Long Island, N. Y., represents a range extension of about 800 nautical miles northward from Florida along the Atlantic coast of the United States.

### 3. *Myripristis jacobus* Cuvier. Blackbar soldierfish

Three specimens (101-142 mm S.L.) from *Combat* station 353 and *Silver Bay* station 3009. Range previously reported as "Both sides of the Atlantic; in the western Atlantic from the northeastern Gulf of Mexico to Tortugas, Florida, and south to Rio de Janeiro" by Briggs (1958, p. 270). The collection of the specimen off Jacksonville Beach, Fla. (*Combat* station 353), represents a range extension of about 500 miles by sea from Tortugas.

### 4. *Ostichthys trachypomus* (Günther). Bigeye soldierfish

One specimen (29 mm S.L.) from *Silver Bay* station 4117 and three specimens (22-25 mm S.L., deposited in the U. S. National Museum) collected by Robert H. Gibbs, Jr. with dipnet and night light, while aboard the *Delaware* 38°05′N. Lat., 65°58′W. Long. (USNM 194245) and 39°44.5′N. Lat., 70°56′W. Long (USNM 194246). Range previously reported as West Indies and Cuba by Jordan, Evermann, and Clark (1930, p. 234). Bailey et al. (1960, p. 24) first listed this species as occurring in waters of the United States presumably based upon a previously unpublished record off North Carolina furnished by Loren P. Woods. The collection of the specimens (USNM 194246) from SE of Montauk Pt., Long Island, N. Y., represents a range extension of about 900 nautical miles northward from the northernmost part of the West Indies (Bahamas), along the Atlantic coast of the United States.

### 5. *Anisotremus virginicus* (Linnaeus). Porkfish

Three specimens (82-260 mm S.L.) from *Silver Bay* stations 5516 and 5682. Range previously reported as "Bermuda and southern Florida to Santa Catarina, Brazil, and the eastern and southern Gulf of Mexico" by Briggs (1958, p. 279). The collection of the specimens off Anastasia Is., Fla. (*Silver Bay* station 5682), represents a range extension of about 200 nautical miles northward from southern Florida along the Atlantic coast of the United States.

### 6. *Chaetodon sedentarius* Poey. Reef butterflyfish

Thirty-seven specimens (73-120 mm S.L.) from *Silver Bay* stations 1207, 1233, 1268, 1297, 1506, 1534, 1734, 1738, 2543, 3010, 4652, 4665, 4673, 4921, 4938, 5390, 5391, 5393, 5417, 5420, and 5437. Range previously reported as Bermuda and West Indies by Beebe and Tee-Van (1933, p. 176); as "Eastern and southwestern Gulf of Mexico to Hispaniola" by Briggs (1958, p. 282); from the northern Gulf of Mexico by Collins and Smith (1959, p. 252); and from off the south Atlantic coast of the United States, but with no specific locality given, by Hubbs (1963, p. 140). The collection of the specimen off Cape Lookout, N. C. (*Silver Bay* station 1268), represents the northernmost known occurrence of this species along the Atlantic coast of the United States.

### 7. *Holacanthus tricolor* (Bloch). Rock beauty

Four specimens (115-173 mm S.L.) from *Silver Bay* stations 5418, 5419, and 5420. Range previously reported as "Bermuda and the Florida Keys to Rio de Janeiro" by Briggs (1958, p. 283). The collections of these specimens off Cumberland Is., Ga., represent a range extension of about 300 nautical miles northward along the Atlantic coast of the United States.

### 8. *Bodianus pulchellus* (Poey). Spotfin hogfish

Five specimens (176-231 mm S.L.) from *Silver Bay* stations 4665, 4673, 5417, and 5418. The specimen from *Silver Bay* 4665 is deposited in the Chicago Natural History Museum (CNHM 66683). Range previously reported as "southeastern Florida and the Bahamas to northern South America" by Feddern (1963, p.

227). The collections of the specimens off Cape Romain, S. C. (*Silver Bay* stations 4665 and 4673), represent a range extension of about 450 nautical miles northward of that given by Feddern. The largest specimen examined by Feddern was "156.2" mm (UMML 9508). All specimens collected by the *Silver Bay* were larger but show the total gillraker count given by Feddern to distinguish *Bodianus pulchellus* (15 to 16) from the closely related *Bodianus rufus* (17 to 19). The preserved specimens show distinctive markings similar to those described by Feddern for *B. pulchellus* (a striking black area on the dorsal part of the pectoral distally and a black spot at the bases of the first two to four dorsal spines).

9. *Clepticus parrai* (Bloch and Schneider). Creole wrasse

One specimen (37 mm S.L.) from *Silver Bay* station 4183. Range previously reported as Bermuda and the West Indies by Beebe and Tee-Van (1933, p. 194). Henry A. Feddern (*in litt.*, 16 March 1964) stated that there are "quite a few specimens of *Clepticus parrai*" in the collections of the University of Miami Marine Laboratory; all from the Florida Keys except one found dead on the beach at Miami Beach, Dade County, Florida, on 10 September 1960 (UMML 7140). The collection of this specimen off Cape Fear, N. C., represents a range extension of about 550 nautical miles northward along the Atlantic coast of the United States.

## DISCUSSION

Captures of large *Holocentrus ascensionis* and *Chaetodon sedentarius* from many localities off the south Atlantic coast of the United States in all seasons show they are resident species as far north as northern South Carolina (*H. ascensionis*) and central North Carolina (*C. sedentarius*), whereas the small specimens of *H. ascensionis* dipnetted farther north probably drifted into their areas of capture.

Collections of *Bodianus pulchellus* in January and December 1963 (nearly a year apart) and of *Holacanthus tricolor* in December 1963 during a time of the year when we would not expect warmer water strays, and each at more than one locality, indicate that these species normally range this far north.

*Ostichthys trachypomus* and *Clepticus parrai* may not normally occur as far north as these records suggest. The specimens of each of these species could have developed from pelagic larval forms which drifted into their areas of capture. Their small size and capture in the warmer months (*O. trachypomus* in June, August, and September and *C. parrai* in July) lend credence to this hypothesis.

Increased collecting in progress off the Atlantic coast of the United States will likely reveal that many species now considered sub-tropical or tropical have far more extensive northerly ranges—as strays or random wanderers, as migrants, and as indigenous members of the fauna.

## LITERATURE CITED

BAILEY, REEVE M., et al. 1960. A list of common and scientific names of fishes from the United States and Canada. Am. Fish. Soc., Spec. Publ., no. 2, pp. 1-102.

BEEBE, WILLIAM, AND JOHN TEE-VAN. 1933. Field book of the shore fishes of Bermuda. G. P. Putnam's Sons, 337 pp., illus.

BRIGGS, JOHN C. 1958. A list of Florida fishes and their distribution. Bull. Florida State Mus., vol. 2, no. 8, pp. 223-318.

COLLINS, RICHARD A., AND ROBERT E. SMITH. 1959. Occurrence of butterfly fish in Mississippi Sound. Copeia, no. 3, p. 252.

FEDDERN, HENRY A. 1963. Color pattern changes during growth of *Bodianus pulchellus* and *B. rufus* (Pisces: Labridae). Bull. Mar. Sci. Gulf and Caribbean, vol. 13, no. 2, pp. 224-241.

GIBBS, ROBERT H., JR., AND BRUCE B. COLLETTE. 1959. On the identification, distribution, and biology of the dolphins, *Coryphaena hippurus* and *C. equiselis.* Bull. Mar. Sci. Gulf and Caribbean, vol. 9, no. 2, pp. 117-152.

HOWELL RIVERO, LUIS. 1941. *"Corniger spinosus"* Agassiz: nueva especie para Cuba y algunas consideraciones acerca de la misma. Torreia, no. 6, pp. 3-7.

HUBBS, CARL L. 1963. *Chaetodon aya* and related deep-living butterflyfishes; their variation, distribution and synonymy. Bull. Mar. Sci. Gulf and Caribbean, vol. 13, no. 1, pp. 133-192.

JORDAN, DAVID STARR, BARTON WARREN EVERMANN, AND HOWARD WALTON CLARK. 1930. Check list of the fishes and fishlike vertebrates of North and Middle America north of the northern boundary of Venezuela and Colombia. Rept. U. S. Comm. Fish., 1928, App. X., pp. 1-670.

McKenney, Thomas W. 1959. A contribution to the life history of the squirrel fish *Holocentrus vexillarius* Poey. Bull. Mar. Sci. Gulf and Caribbean, vol. 9, no. 2, pp. 174-221.

*U. S. Bureau of Commercial Fisheries Biological Laboratory, Brunswick, Georgia.* Contribution number 76.

Quart. Jour. Florida Acad. Sci. 27(4) 1964 (1965)

# SOUTHERN SHRIMP . . . A VALUABLE REGIONAL RESOURCE

Value of the shrimp catch to commercial fishermen in North Carolina, South Carolina, Georgia, and Florida east coast during 1960-64 varied from about $8,500,000 in 1960 to about $6,600,000 in 1964. Three shallow-water penaeid shrimps — White, *Penaeus setiferus;* Brown, *Penaeus aztecus;* and Pink (or Brown-spotted), *Penaeus duorarum* — and one deep-water penaeid, the Royal Red, *Hymenopenaeus robustus,* support the most valuable fishery in the south Atlantic States. White and Brown Shrimps are caught in commercial quantities in all four States, Pinks only in North Carolina, and Royal Reds in limited quantities off the Florida east coast in 150 to 200 fathoms. In 1962-64, Royal Red catches varied from 59,000 to 178,000 pounds.

## Gradual Change In Fishing Efficiency

Shrimp gear has not changed basically since the industry was revolutionized by the introduction of the otter or shrimp trawl sometime between 1912 and 1915. In recent years, however, improvements in the trawls, larger and more powerful vessels, and discovery of new grounds have resulted in more efficient operations and expansion of the fishery.

## Catch Fluctuations Are Common

Total catch fluctuated widely in 1960-64 and showed a trend toward steady decline. White Shrimp had been the dominant species in the south Atlantic since the fishery began, but declines in its production resulted in about equal catches of Browns and Whites in 1962-64. The large, year-to-year fluctuations in total catches in North Carolina, South Carolina, and Georgia are remarkably similar in all three States. The conditions causing these fluctuations must exist over the entire three-State area. Florida has experienced a steady decline in total catch during 1960-64. Yearly fluctuations are not necessarily abnormal for a resource that is now being harvested at near-maximum levels. Rather, they depict changes in abundance of fishable stocks available from year to year, and these changes reflect several factors influencing survival of the young — for we are dealing with a new crop of shrimp each year.

## Management A State Responsibility

Towards the end of 1946, the Atlantic States Marine Fisheries Commission began to develop a management plan for shrimp for the south Atlantic States. The Commission's interest in the plan has not slackened. Today, aided by the Commission's work, the four States have reasonable management plans, for the most part based on protecting young and small shrimp.

*North Carolina,* in principle, regulates the seasons by opening areas to fishing when the shrimp reach commercial size. During the open season, shrimping is allowed in inside waters. The State depends on the Institute of Fisheries Research of the University of North Carolina for information enabling it to decide when to open or close its inside and outside waters.

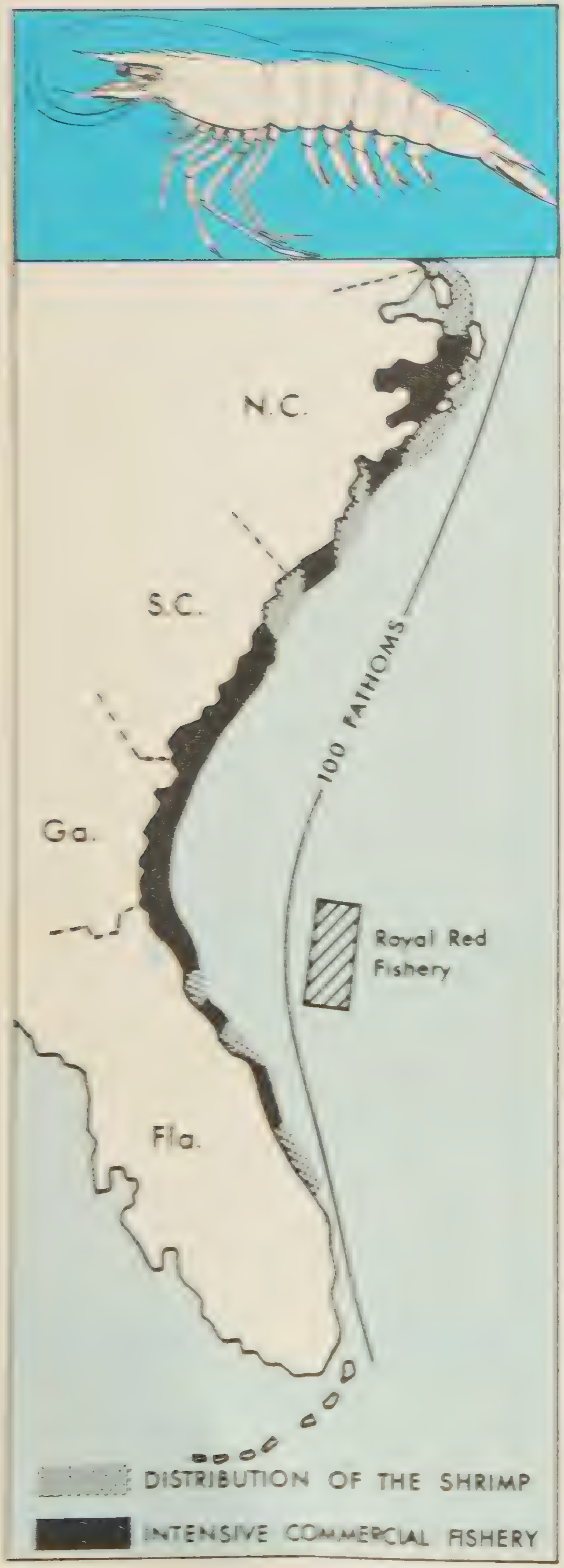
*South Carolina* has shrimping seasons to protect the young shrimp and the nursery grounds. The outside shrimping season is March 15 to December 15, and if the Bears Bluff Laboratories recommends, the State can shorten or extend the season by 30 days. Inside waters, primarily the large sounds, are open August 15 to December 15, and again, the State can shorten or extend the season. The extensions are Statewide — all sounds are either open or closed.

Contribution No. 78
U. S. Fish & Wildlife Service
Bureau of Commercial Fisheries
Biological Laboratory
Brunswick, Georgia

MARINE RESOURCES OF THE ATLANTIC COAST

Leaflet Number 4, October 1965

ATLANTIC STATES MARINE FISHERIES COMMISSION, 336 East College Avenue, Tallahassee, Florida 32301



*Georgia* waters are closed to shrimping from January 1 to March 15, but the State can open any portion of the offshore waters when the shrimp are larger than 55 count (i.e., 55 shrimp per pound), heads on. Three of the major sounds in Georgia are open to shrimping from March 16 to December 31, but the State can close these areas when the shrimp are smaller than 55 count. Special County elections, held not more often than every 2 years, can open or close shrimping in sounds from March 16 to December 31. Generally, trawling with small nets for bait shrimp is not restricted except in Doboy Sound (closed to commercial bait fishing) and the rivers and creeks in Chatham County (closed to trawling).

*Florida* prohibits commercial shrimping in the inside waters on the east coast. Some dragging is done for bait shrimp, however; restrictions on bait shrimping vary in different Counties. Offshore waters along the east coast have no closed season. Night shrimping is restricted September to May. If conditions warrant, State can close any area to shrimping, but seldom does so on the east coast.

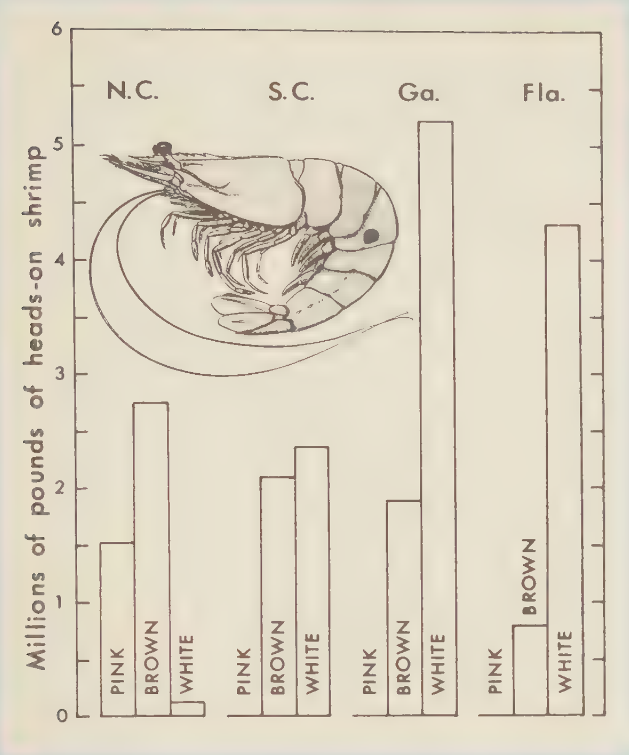
## Life Cycle Of White Shrimp

The life cycle of the White Shrimp is better known than those of the Brown and Pink Shrimps, and provides an example of the biology of the important commercial species.

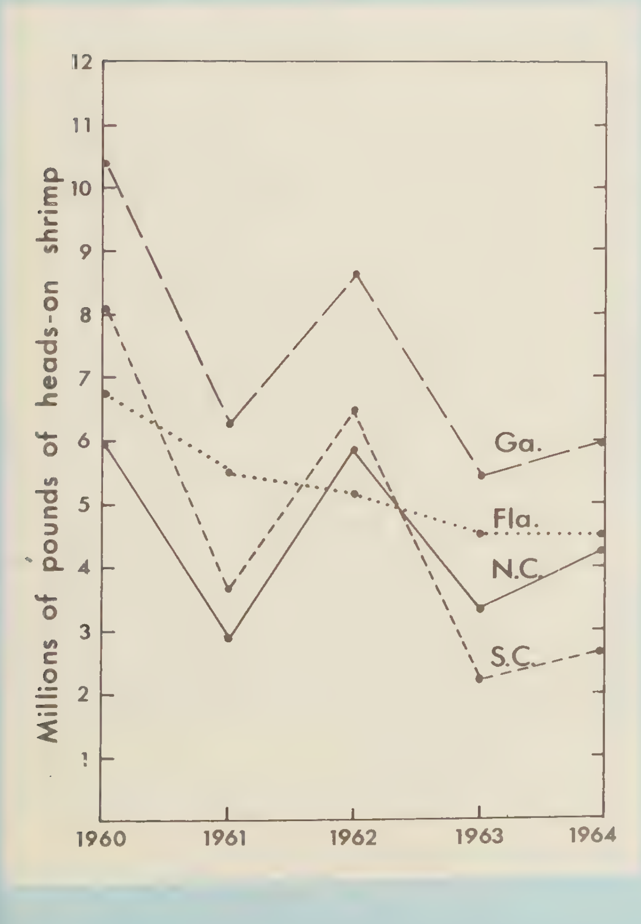
*Habitat.* The White Shrimp is most abundant in areas characterized by an inland, brackish marsh connected by passes with an adjacent shallow, offshore area of relatively high salinity and mud or clay bottom.

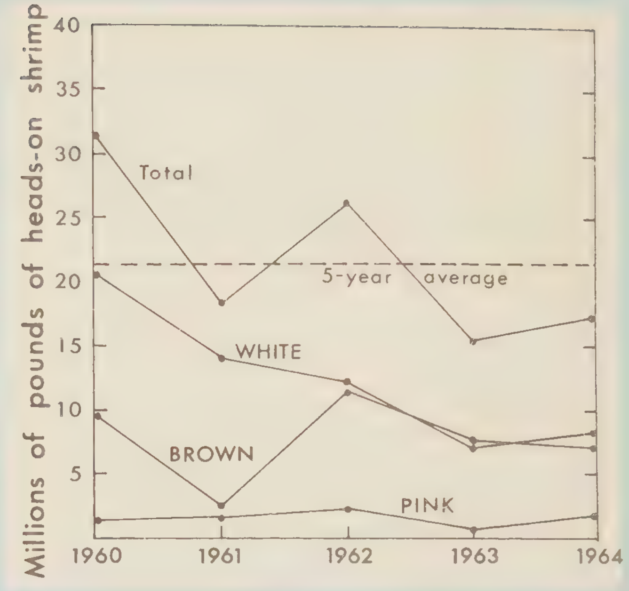
*Spawning.* Eggs are laid directly into the water and are apparently fertilized by spermatozoa contained in a capsule (spermatophore) that the male attaches to the female. A female lays 500,000 to 1 million eggs at a spawning — some females probably spawn more than once in a season. Most, if not all, spawning takes place at sea, mainly from late March or early April to the end of September.

*Eggs and larvae.* The eggs are about 1/75-inch in diameter and demersal. Eggs hatch in about 20 to 24 hours, and the nauplius, which resembles a tiny mite, emerges and becomes planktonic. Larval development requires 2 to 3 weeks. After 15 or 20 days and two postlarval stages, the young shrimp is only about 1/5-inch long and has moved from the saline offshore spawning area to the brackish inside marshes and estuaries that serve as nursery grounds.

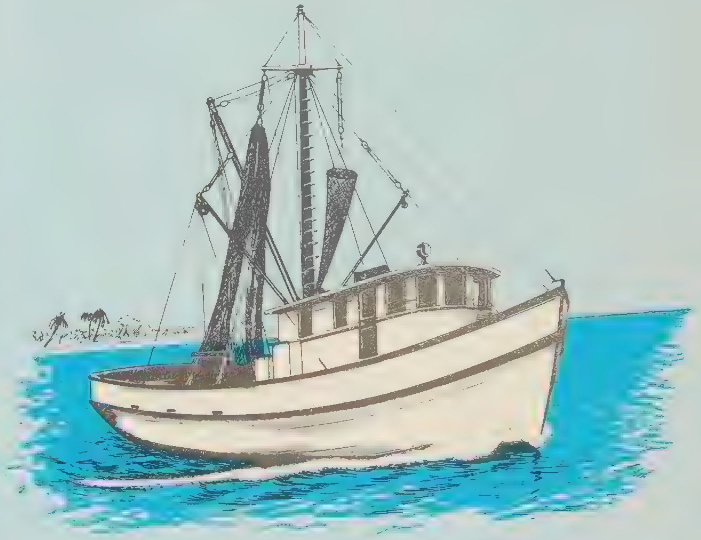


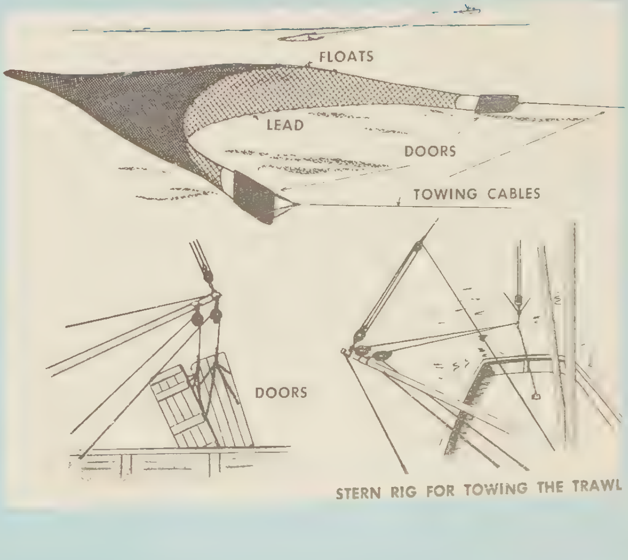
The 5-year average (1960-1964) of the shrimp catch, by species for each state, is shown above; the harvest, all species combined, is shown below.





The total catch for each species, all states combined, is graphed above for the years 1960 through 1964. A modern shrimp trawler and shrimp-trawling gear are shown below.




FLOATS
LEAD
DOORS
TOWING CABLES
DOORS
STERN RIG FOR TOWING THE TRAWL

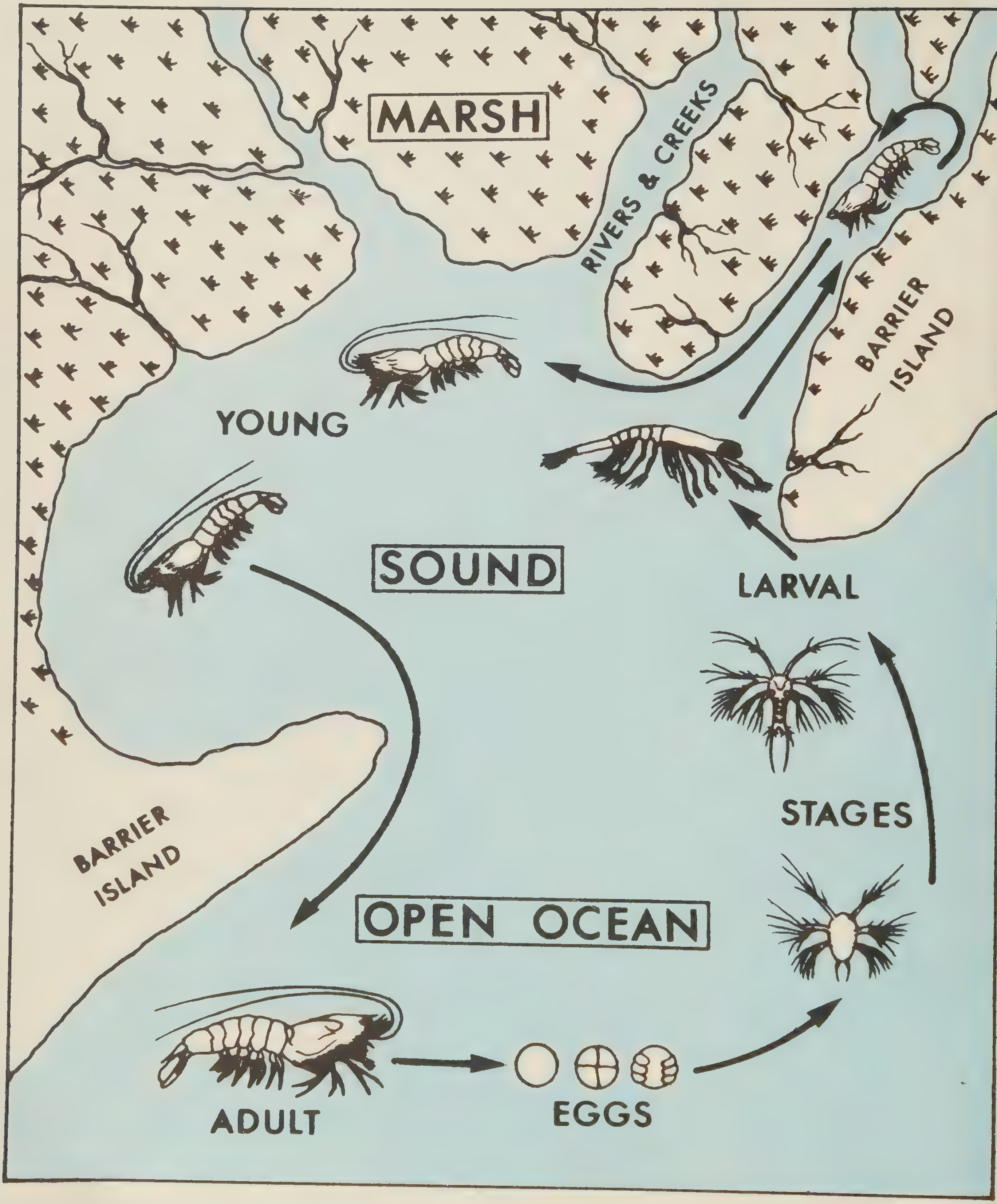

MARSH
RIVERS & CREEKS
BARRIER ISLAND
YOUNG
SOUND
LARVAL
STAGES
BARRIER ISLAND
OPEN OCEAN
ADULT
EGGS

DIAGRAM OF THE LIFE CYCLE OF THE WHITE SHRIMP

(cycle occurs in a 12-month period)

*Young shrimp.* As the young grow, they move from the shallow waters of the marsh into the deeper creeks, rivers, and sounds; they first appear on the inside fishing grounds in June or July when about 2 inches long. By July or August they begin to appear in outside waters.

*Growth.* Growth is rapid from spring to early fall, but negligible in winter. A shrimp is about 3 inches long 2 months after hatching. A shrimp hatched on May 1 is over 6 inches long by November 1, grows little during winter, resumes growth in the spring, and is about 7 inches long by May 1. It is then about 1 year old and begins spawning.

*Migrations.* In the south Atlantic area, most White Shrimp do not move into deep water far from the coast after migrating from inshore to offshore waters. Instead, they move parallel to the shoreline — southward in fall and early winter and northward in late winter and early spring.

*Longevity.* Mortality is apparently high, and few live more than 1 year. Some shrimp live at least 16 months and possibly longer, but as far as the fishery is concerned, White Shrimp can be considered an annual crop.

## Larval Lives Of Shallow-water Shrimp

The White, Pink, and Brown Shrimps along the Atlantic and Gulf coasts have generally similar natural histories despite their marked, specific differences. Although much is unknown about larval shrimp, it is apparent that the early stages of all three species are a part of the oceanic plankton, drifting about and feeding chiefly upon microscopic phytoplankton (diatoms, etc.). Within 2 weeks after hatching the young shrimp becomes a postlarva which is an active swimmer and manages to reach the shallow estuarine nursery areas.

## Food Habits Change With Growth

Soon after reaching the nursery areas, the postlarva descends to the bottom. Formerly a plankton feeder, it now becomes a bottom feeder, consuming algae, bottom invertebrates, and plant and animal debris. This omnivorous feeding continues through the adult stage. (The larger shrimp feeds on the same type of food as the bottom-dwelling postlarva and early juvenile, except that larger organisms such as worms and mollusks are also eaten.)

The bottom-dwelling postlarva soon becomes a juvenile. Growth is very rapid, particularly when water temperatures exceed 70°F. As the shrimp grows, it moves gradually seaward, presumably in response to salinity or habitat preferences. By the time the shrimp is an adult, it is moving out of the estuarine areas into the ocean. Most Brown Shrimp, which enter costal waters as postlarvae in winter and early spring, move offshore during late summer and fall; by late fall practically none remain inshore. Large White Shrimp, and to a certain extent Pink Shrimp, enter inshore waters as postlarvae in late spring and summer and move offshore in late fall and winter. Many juveniles and subadults of these species remain inshore throughout the winter, and spawn the following spring. Temperature and salinity appear to be major factors influencing the inshore, offshore, and coastwise movement of all these species.

## Predation Is Important

Many species of fish and other animals prey upon shrimp during the various stages of their life cycle. Eggs and early larvae are consumed by predators such as arrowworms and larval fishes; postlarvae and early juveniles are preyed upon by postlarval and juvenile fishes such as croaker, spot, and flounder. Larger shrimp are eaten by many enemies, chief among which are the seatrouts, silver perch, and other sciaenid fishes.

## Shrimp Differ In Their Habitat Preference

Aside from differences in time and place of spawning, perhaps the most marked dissimilarities among the White, Pink, and Brown Shrimps are those of habitat preference and behavior. Pink Shrimp seem to prefer higher salinities and coarse bottoms of coral mud or sand and shell. White Shrimp, on the other hand, appear to thrive best in more brackish waters with a highly organic soft-mud bottom. Brown Shrimp also prefer mud bottom, but grow faster at fairly high salinities. Brown and Pink Shrimp (but seldom White Shrimp) tend to burrow into the substrate, particularly during the daytime. White Shrimp are the most active and the least hardy of the three species, and are also most susceptible to low temperatures.

## Locomotion Is Varied

All three species of shrimp have the same means of locomotion: (1) crawling on bottom by using the front "walking" legs; (2) swimming by using five pairs of abdominal swimmerets; and (3) moving quickly by suddenly flipping the tail section, which propels the shrimp backwards.

## Research Is Active

*North Carolina.* Shrimp research for the past several years has been carried on by the Institute of Fisheries Research. It has been concerned with: (1) postlarval recruitment into sounds; (2) trends in abundance of postlarvae within and among years; (3) relation of abundance of postlarvae to commercial catch; and (4) possible effect of measurable meteorological and hydrographical events on abundance levels.

*South Carolina.* Since 1953, South Carolina, through Bears Bluff Laboratories, has been studying the relative abundance of shrimp at some 20 offshore and inshore index stations. Data are obtained by the standard trawls of Bears Bluff's research boats. Plankton tows at the index stations and in many other areas throughout the State provide information for managing shrimping. Since 1959-60 the Laboratories have been predicting the commercial catch of shrimp with considerable accuracy. Other research has been on the development of pond cultivation of shrimp. Rather small-scale offshore explorations were carried on in 1955-58 to attempt to locate concentrations of shrimp.

*Georgia.* Research has been confined largely to basic research at the University of Georgia on the influence of light on the behavior and photomechanical visual processes of two species of penaeid shrimp.

*Florida* (East coast). The State Board of Conservation has carried on a shrimp-sampling study for 2½ years near St. Augustine. Studies of Brown Shrimp off Melbourne are contemplated.

*Federal Government.* The Bureau of Commercial Fisheries Biological Laboratory at Brunswick, Ga., is studying the biology of Royal Red Shrimp.

The Exploratory Fishing and Gear Research Station of the Bureau of Commercial Fisheries is conducting exploratory fishing off the South Atlantic States. This continuing work has yielded considerable information on the relative abundance of commercial shrimp at different depths off the coast. For example, early in 1965 a concentration of large adult shrimp (mostly Brown but also some Pink) was found in about 30 to 40 fathoms of water off Cape Kennedy, Fla.

## More Research Is Essential

The shrimp industry along the south Atlantic coast suffers from largely unexplainable fluctuations in the annual harvest. All indications are that fluctuations result from environmental factors such as weather (temperature and rainfall) and man-made changes in the physical environment. Research aimed at pinpointing the exact relation between shrimp populations and their physical environment, particularly temperature, should be expanded. Continuous recordings of offshore temperature seem particularly essential. Cultivation of shrimp in controlled environments, as has been started in South Carolina, should be continued and emphasized, because it seems to be one of the less complicated ways of determining the effects of physical environment on the species.

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# Sex Ratios and Sexual Dimorphism Among Recently Transformed Sea Lampreys, *Petromyzon marinus* Linnaeus[1]

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## ABSTRACT

The sex, length, and weight were determined of nearly all recently transformed sea lampreys migrating downstream in the Carp Lake River, Michigan, in the fall, winter, and spring of 1960–61. Similar data were collected from samples of an earlier run in the Carp Lake River and of runs in three other tributaries of Lakes Huron and Michigan. The sex ratio of the 1960–61 migrants in the Carp Lake River was 324 males:100 females. Sex ratios of migrants in the other runs varied from 77 to 86 males:100 females. The high proportion of males in the 1960–61 run in the Carp Lake River is attributed to the effective prevention of recruitment of sea lampreys in the river and transformation of the females at an earlier age than is characteristic of the males. A near equal sex ratio among recently transformed migrants is considered normal for the species. The sex composition of a run changed during the period of migration. The proportion of males among the migrants was greatest at the beginning of the run and declined steadily thereafter. The average size was smaller for males than for females. Differences in the mean lengths and weights of the sexes were statistically significant. The length–weight relation differed for the sexes and showed a slower rate of increase of weight with increase in length than is characteristic of other stages of the animals' life cycle. Seasonal changes in the length–weight relation had a trend toward lower weights among the migrants coming downstream in the later months of the run.

## INTRODUCTION

Researches on the life history of the parasitic sea lamprey (*Petromyzon marinus*) in the upper Great Lakes and on methods for its control have included much attention to the spawning runs of adults into streams. Records have been kept of the total numbers and the sex and size of spawning migrants entering the Ocqueoc River, Presque Isle County, Michigan, nearly every year since 1947. Similar records, covering shorter spans of years, have been collected for many additional tributaries of Lakes Huron, Michigan, and Superior. Early reports of these data were made by Applegate (1950), Applegate and Smith (1951), Applegate *et al.* (1952), and Erkkila *et al.* (1956); much of the information for later years has not been published.

Pronounced changes in sex composition with changes in the abundance of spawning migrants in successive years were described in these reports.

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Printed in Canada.

Subsequently, Applegate (unpublished data) demonstrated that abundance and the ratio of males to females were positively correlated in Ocqueoc River spawning runs, i.e. the greater the number of mature migrants the larger was the proportion of males. Hardistry (1961a) observed the same correlation between abundance and sex ratio in spawning populations of the nonparasitic *Lampetra planeri* in the River Yeo in England. He showed further the similarity of this relationship in the two species with data on the Great Lakes sea lamprey provided him for this purpose.

Differences in the life cycle of *L. planeri* (nonparasitic as an adult) and the sea lamprey (parasitic as an adult) make difficult any speculation about the factor or factors regulating sex composition among populations of the mature individuals. It is possible that a common explanation of the relation between population density and sex ratio will not be found for the two species. Unquestionably, any search for causal factors will be aided by a knowledge of the sex composition of larval populations and, for the sea lamprey, of downstream runs of recently transformed individuals.

The only significant report of sex ratios among larval populations is that of Hardisty (1960a) for *L. planeri*, *L. fluviatilus*, and *P. marinus*. In a small sample of larval sea lampreys taken from the Ocqueoc River, Michigan, he found an approximately equal sex ratio (48.6% males). No comparable information has been available for populations of sea lampreys immediately following their metamorphosis. Applegate (1950, 1961) and Applegate and Brynildson (1952) described the downstream runs of recently transformed sea lampreys in the Carp Lake River, Michigan, but they did not determine the sex of the individual migrants.

This report describes the sex composition of an entire downstream run of recently transformed sea lampreys in the Carp Lake River and of samples of migrating or sedentary populations of the same life-history stage in this and in three other Great Lakes tributaries. It also describes sex differences among downstream migrants in organ development, morphometry, and time of migration.

## MATERIALS AND METHODS

### Collection of Specimens

An inclined-screen trap for the capture of downstream-migrating sea lampreys and fishes was operated almost continuously in the Carp Lake River, a tributary of the Straits of Mackinac in Emmet County, Michigan, from April 1948 until September 1961 (Applegate and Brynildson, 1952; Applegate, 1961). During the fall, winter, and spring of 1960–61, a downstream run of 8925 recently transformed sea lampreys was taken in this device. Few, if any, migrants are believed to have escaped the trap during this season (Thomas M. Stauffer, Michigan Department of Conservation, personal communication). Of the total number of lampreys captured, 8793 or 98.5% of the run were available for this study. Samples of an earlier downstream run, captured in this river in 1956–57, were also at hand. These consisted of 370 migrants

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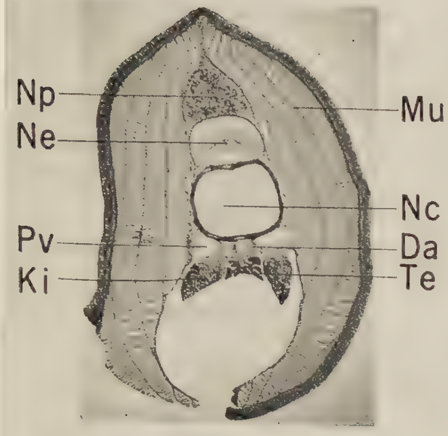

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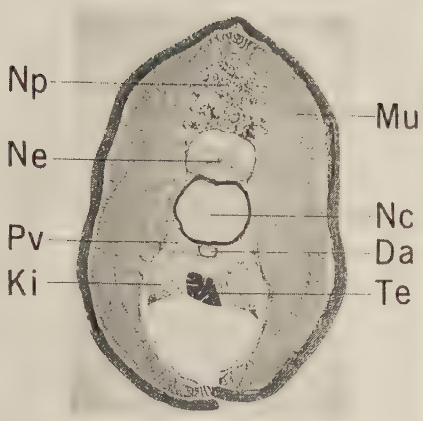

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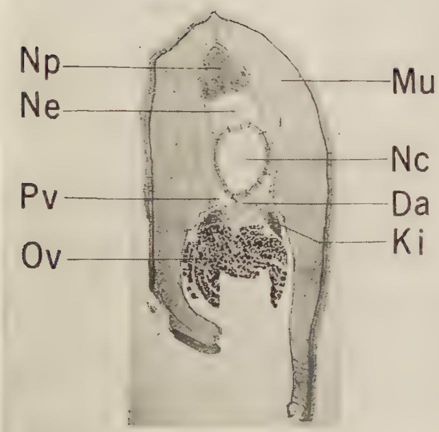

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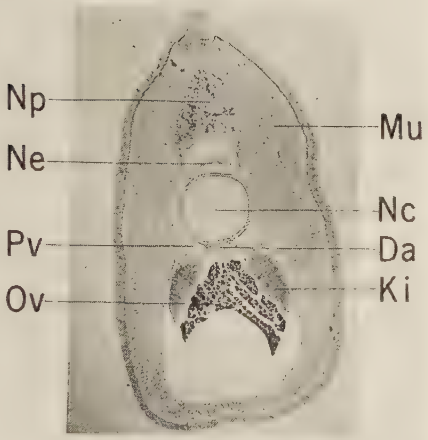

FIG. 1. Cross section of recently transformed male sea lamprey at anterior portion of body cavity (× 16). Alimentary canal removed before sectioning. Kidney in this body area is small and composed largely of nephric tubules. Da = dorsal artery; Ki = kidney; Mu = trunk musculature; Nc = notochord; Ne = neural cord; Np = neural process; Pv = post cardinal vein; Te = testis.

FIG. 2. Cross section of recently transformed male sea lamprey at posterior portion of body cavity. Alimentary canal removed before sectioning. Kidney in this area is large (lobed) and composed primarily of adipose tissue. Legend the same as in Fig. 1.

FIG. 3. Cross section of recently transformed female sea lamprey at anterior portion of body cavity. Alimentary canal removed before sectioning. Kidney in this body area is small and composed largely of nephric tubules. Ov = ovary; remainder of legend the same as in Fig.1.

FIG. 4. Cross section of recently transformed female sea lamprey at posterior portion of body cavity. Alimentary canal removed before sectioning. Kidney in this area is large (lobed) and composed primarily of adipose tissue. Ov = ovary; remainder of legend the same as in Fig. 1.

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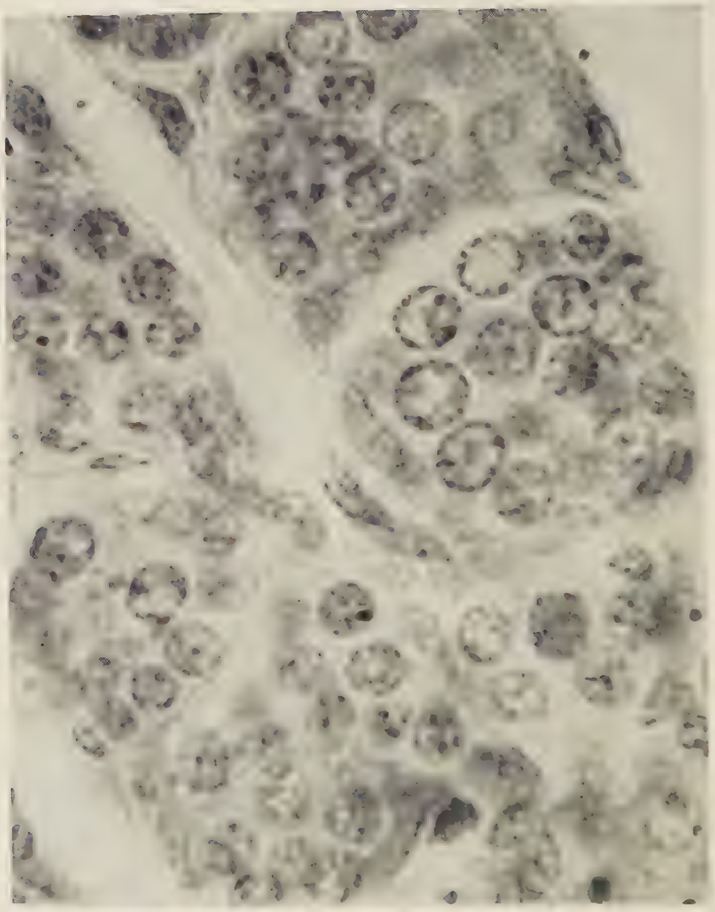

Fig. 5. Section of the testis of a recently transformed male sea lamprey, showing spermatogonial cells (× 1200). Specimen was 144 mm, total length, and was captured moving downstream in the Ocqueoc River in March 1964.

collected at random in November and December 1956 and April and May 1957 from a total run of at least 2640 lampreys (Applegate, 1961).

Samples of populations of recently transformed sea lampreys in three other widely separated tributaries of Lakes Huron and Michigan were taken by several means. The largest collection consisted of 1862 downstream migrants of the 1962–63 run in the Pere Marquette River, a large stream flowing into Lake Michigan on its east-central shore in Mason County, Michigan. These lampreys were captured in a trap set in the water intake of a Dow Chemical Company plant about ¼ mile from the mouth of the river along the shore of Pere Marquette Lake. Of the total sample, 1235 specimens were caught between November 11 and 24, 1962, and 627 between February 11 and April 15, 1963.

Fyke nets took 408 downstream migrants of the 1962–63 run in the Ocqueoc River, a tributary of northern Lake Huron in Presque Isle County, Michigan. Of these lampreys, 119 were caught between December 3 and 10, 1962, and 289 between March 11 and April 10, 1963.

Transformed and partly transformed sea lampreys collected just prior to their downstream migration while they were still sedentary in the stream bed were obtained from the Ogontz River, Delta County, Michigan. This small stream, which enters Lake Michigan on its northwest shore, was treated with a selective lamprey larvicide on August 30–September 1, 1960 (Smith and McLain, 1962). Of the 576 transformed or partly transformed individuals picked up at random throughout the river system during the treatment, we examined 527.

With one exception, all lampreys were fixed in 10% formalin at the time of collection. Eighty-seven of the specimens taken in the Carp Lake River in 1956–57 were fixed in Bouin's solution and then transferred to 70% alcohol.

## Determination of Sex

Sex differences are known to exist in the development of the reproductive organs of lampreys. Unfortunately, specific events and the time of their occurrence in the development of the gonads have not been defined clearly for any species. Okkelberg (1921) showed that ammocoetes of *Entosphenus wilderi* (Gage)[2] passed through an indeterminate or indefinite sex phase during their first year or so of life. At this stage mitotic divisions of the germ cells took place. Later all individuals entered a phase characterized by some meiotic divisions resulting in the formation of oocytes. This process continued in specimens destined to become females until the full complement of oocytes was formed. The production of oocytes in males ceased, however, and the gonad remained in a resting state with spermatogonia as the only vital germ cells; the oocytes that had already formed either degenerated or remained rudimentary. Meiotic maturation divisions preliminary to the formation of spermatozoa did not take place until a few months before spawning. More recent studies of the ammocoetes of other species suggest that this course of events is fairly typical of all lampreys, i.e. the two sexes are at very different stages of sexual development at the time of metamorphosis (Hardisty, 1960a, b, 1961b; Zanandrea, 1957).

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[2] Now called *Lampetra lamottei* (LeSueur).

Hardisty (1960b) has reported that a definitive ovary or testis can be found in ammocoetes of the sea lamprey that have a total length over 90 mm. Our examination of the gonads of recently transformed sea lampreys proved that the sex of the individuals is readily distinguishable. We have found further that sex differences in gonadal development are sufficiently pronounced to permit rapid and accurate macroscopic identification.

Microscopic examinations verified the accuracy of macroscopic determination of sex. Specimens for microscopic study were fixed either in Bouin's solution or in 10% formalin. Blocks were cut from various locations along the central part of the body, dehydrated by standard methods, embedded in paraffin wax, softened in Mollifex (B.D.H.), and then sectioned at 10 $\mu$ on a rotary microtome. Sections were stained with haematoxylin and counterstained in eosin.

Under low magnification, the cross-section of the gonad in the recently transformed male sea lamprey is small and evenly shaped and has a fine structure (Fig. 1 and 2). That in the female, on the other hand, is large and horseshoe-shaped and usually projects to some extent around both sides of the alimentary canal (Fig. 3 and 4). The oocytes in the female gonad are large and are visible in most specimens even under a hand lens. Germ cells in the testis have not progressed beyond the spermatogonial stage and can be seen only under high magnification (Fig. 5).

To develop a macroscopic technique for determining the sex of the bulk of the lampreys discussed in this report, we initially cut numerous thick, transverse sections through the body cavity for examination with binocular microscopes and hand lenses. Subsequently, we found it necessary only to make a single transverse cut through the ventral half of the body at a point opposite the anterior end of the dorsal fin. The body was then folded back for examination of the viscera by eye alone or with low-power hand lenses. Females were identified by the large ovary, with its discernible oocytes, that appears as a relatively dark, gray-colored organ in both fresh and formalin-preserved specimens. Males were distinguished by the small testis that appears creamy-white and has a much lighter color than the ovary.

### Length and Weight

Measurements of total length were made to the nearest millimeter on conventional fish-measuring boards. Weights were determined to the nearest 0.1 g on Ohaus triple-beam balances.

## SEX COMPOSITION

Of the 8925 recently transformed downstream migrants taken in the Carp Lake River trap in 1960-61, the sex was determined for 8780 individuals or 98.4% of the total run. Of these 8780 lampreys, 6710 or 76.4% were males and 2070 or 23.6% were females. This is a ratio of 324 males:100 females (Table I). The sex composition of this run differed significantly from that of the run in the same river 5 years earlier. In a sample of 370 migrants captured in the Carp Lake River in 1956–57, 171 or 46.2% were males and 199 or 53.8% were females (ratio of 86 males:100 females — Table II). The proportion of males (or females) in samples of migrant and sedentary stocks of recently transformed sea lampreys collected in recent years in three other Great Lakes tributaries was similar to that for the Carp Lake River migrants in 1956–57. The sex ratio of the migrants of the 1962–63 run in the Pere Marquette River

TABLE I. Numbers of males and females and sex ratios among recently transformed sea lampreys migrating downstream in the Carp Lake River, Michigan, during semi-monthly periods in the fall, winter, and spring of 1960–61.

| Semi-monthly period (1960–61) | Total number of migrants[a] | Number of males | Number of females | Sex ratio | |
|---|---|---|---|---|---|
| | | | | Males:females | Percentage males |
| Sept. 15–30[c] | 1 | 1 | 0 | – | 100.0 |
| Oct. 1–15 | 12 | 12 | 0 | – | 100.0 |
| 16–31 | 721 | 584 | 137 | 426:100 | 81.0 |
| Nov. 1–15 | 4050 | 3126 | 924 | 338:100 | 77.2 |
| 16–30 | 3049 | 2295 | 754 | 304:100 | 75.2 |
| Dec. 1–15 | 346 | 263 | 83 | 317:100 | 76.0 |
| 16–31 | 62 | 45 | 17 | 265:100 | 72.6 |
| Jan. 1–15 | 30 | 16 | 14 | 191:100[b] | 65.6[b] |
| 16–31 | 34 | 26 | 8 | | |
| Feb. 1–15 | 9 | 8 | 1 | 260:100[b] | 72.2[b] |
| 16–28 | 9 | 5 | 4 | | |
| Mar. 1–15 | 126 | 86 | 40 | 215:100 | 68.3 |
| 16–31 | 298 | 222 | 76 | 292:100 | 74.5 |
| Apr. 1–15 | 30 | 19 | 11 | 175:100[b] | 63.3[b] |
| 16–30[c] | 3 | 2 | 1 | | |
| Grand totals and averages | 8780[a] | 6710 | 2070 | 324:100 | 76.4 |

[a] Does not include 13 individuals for which sex was not determined.
[b] Data combined for monthly period because of small number of specimens.
[c] The first migrant was taken on Sept. 25, 1960; the last on April 28, 1961.

TABLE II. Numbers of males and females and sex ratio among samples of recently transformed sea lampreys collected in four Great Lakes tributaries.

| Location and dates of collection | Total number of specimens | Number of males | Number of females | Sex ratio: Males:females | Sex ratio: Percentage males |
|---|---|---|---|---|---|
| *Carp Lake River* | | | | | |
| Nov.–Dec. 1956 | 234 | 117 | 117 | 100:100 | 50.0 |
| Mar.–Apr. 1957 | 136 | 54 | 82 | 66:100 | 39.7 |
| Total sample: 1956–57 | 370 | 171 | 199 | 86:100 | 46.2 |
| *Pere Marquette River* | | | | | |
| Nov. 11–24, 1962 | 1235 | 488 | 747 | 65:100 | 39.5 |
| Feb. 14–Apr. 15, 1963 | 627 | 280 | 347 | 81:100 | 44.7 |
| Total sample: 1962–63 | 1862[a] | 768 | 1094 | 70:100 | 41.2 |
| *Ocqueoc River* | | | | | |
| Dec. 3–10, 1962 | 119 | 54 | 65 | 83:100 | 45.4 |
| Mar. 11–Apr. 10, 1963 | 289 | 120 | 169 | 71:100 | 41.5 |
| Total sample: 1962–63 | 408[a] | 174 | 234 | 74:100 | 42.6 |
| *Ogontz River* | | | | | |
| Aug. 31–Sept. 1, 1960 | 527[b] | 233 | 294 | 79:100 | 44.2 |

[a] Downstream migrants.

[b] Not migrant individuals; collection made during chemical treatment of stream with a selective lamprey larvicide.

was 70 males:100 females while that of the migrants in the Ocqueoc River in the same season was 74 males:100 females. The recently transformed but still sedentary sea lampreys taken from the Ogontz River in the early fall of 1960 had a sex ratio of 79 males:100 females (Table II).

We believe that the ratio of 324 males:100 females in the 1960–61 run in the Carp Lake River is atypical of the sex composition of recently transformed sea lamprey populations in Great Lakes streams. We attribute the high proportion of males in this run to (a) the effective prevention of recruitment to the larval populations in that stream for approximately 6 years immediately prior to the run and (b) to a heretofore unsuspected (and as yet unproven) feature of the sea lamprey's life history, viz. that the females transform at an earlier age than do the males.

The dam and inclined-screen trap constructed near the mouth of the Carp Lake River in 1948 was intended not only to capture recently transformed downstream migrants but also to block the upstream spawning migration of mature sea lampreys and thus prevent subsequent additions to the larval populations of the stream. Unfortunately, some escapement of spawning migrants above the dam and consequent recruitment to the larval populations seems to have occurred at least through 1954 (Applegate, 1961; Stauffer, MS, 1956). According to Stauffer (1962), however, no recruitment occurred above the dam in 1955–61. On the basis of this conclusion, he stated further that the migrants of the 1960-61 downstream run for which we have reported the sex composition were at least 7 years old (1954 year-class). In the 5-year interval between the run of 1956–57 and that of 1960–61, the ratio of males to females in the downstream migrants increased nearly four-fold. In the absence of any recruitment for nearly 7 years, this pronounced shift in the sex composition of the runs can mean only that the females transformed and left the stream at an earlier age than did the males. This conclusion would be valid regardless of whether the 1960–61 downstream run was composed of one (1954 ?) or of several successive year-classes.

The ratio of 86 males:100 females in our sample of the 1956–57 downstream run in the Carp Lake River is unquestionably more nearly typical of populations of recently transformed sea lampreys since it agrees closely with the sex ratios in the collections from the Pere Marquette, Ogontz, and Ocqueoc Rivers where spawning and recruitment to the larval populations have been either largely unhampered or ineffectively prevented (Table II). The spawning runs of adult sea lampreys have been under some measure of control in the Pere Marquette and Ogontz Rivers in only 2 years. Electromechanical weirs and traps to block and capture the spawning-run migrants were operated in both rivers in 1958 and 1959. The supervisors of the operation of these two devices believe that some adults escaped to the spawning grounds in both years in both rivers. Either a mechanical or an electromechanical weir and trap for the capture and destruction of spawning migrants was operated in the Ocqueoc River in 10 of the 12 spring spawning seasons between 1949 and 1960. Some adults are known to have escaped this device and reached the spawning grounds in every year that the barrier was operated. Collections of larval lampreys made regularly in this river have never revealed complete elimination of recruitment in any year. We conclude from the similarity of the sex ratios in these four collections, made over a span of 7 years from widely separated streams, that populations of recently transformed sea lampreys in Great Lakes streams are normally characterized by a small but variable preponderance of females.

## SEX DIFFERENCES IN TIME OF MIGRATION

The sex composition of the recently transformed sea lampreys of the Carp Lake River changed greatly during the migration in 1960-61. The proportion of males among the migrants was greatest at the beginning of the run and declined irregularly but with a clear trend thereafter (Table I). The occasional individuals taken during the early weeks of the movement between September 25 and October 15, 1960, were all males. Females began to move downstream in mid October and their relative numbers increased until they comprised approximately one-third of the migrants captured in the last weeks of the migration in April 1961. Evidence has been presented previously that the great predominance of males in this run is not typical in populations of recently transformed sea lampreys. Consequently, the series of sex ratios given by us in Table I for successive intervals of the migration are not descriptive of the normal proportions of males and females. They do serve, nevertheless, to illustrate a differing trend in the time of downstream movement of the sexes.

Samples of two other runs give further indication of this sex difference in time of migration. The number of males and females was equal in the migrants collected in the Carp Lake River in November and December 1956. Another collection toward the end of this run in March and April 1957 included only 39.7% males (Table II). The downstream run of 1962–63 in the Ocqueoc River showed a similar change in sex ratio. The recently transformed sea lampreys captured in this river in December 1962 were 45.4% male. Among later migrants of March and April 1963, the percentage of males has declined to 41.5.

Samples of the 1962 -63 run in the Pere Marquette River showed a change in sex composition opposite that in the other runs. Of the migrants taken in this river in November 1962, 39.5% were males, but a later collection, made during February, March, and April 1963, had 44.7% of males. We can offer no explanation for the differing trend in the time of migration of the males and females in this run.

## LENGTH, WEIGHT, LENGTH–WEIGHT RELATION, AND SEASONAL DIFFERENCES IN SIZE OF DOWNSTREAM MIGRANTS

### Length and Weight

The length and weight were determined for 8682 recently transformed sea lampreys (6630 males and 2052 females) from the Carp Lake River in 1960–61.

The males in this run were smaller than were the females. Total lengths of males ranged from 104 to 175 mm and averaged 145.0 mm (S.D. = ±8.3). Females ranged from 106 to 179 mm and averaged 148.0 mm (S.D. = ±8.2). The mean weight of the males was 4.6 g (S.D. = ±0.75); they varied from 1.6 to 7.7 g. Females averaged 4.9 g (S.D. = ±0.75) and ranged from 2.2 to 8.0 g. The frequency distributions of the lengths and weights of both males and females were all unimodal and highly symmetrical (Fig. 6 and 7). Characteristics of the length distribution for each sex agree closely with those reported for the combined males and females of downstream runs in earlier years in this river (Applegate and Brynildson, 1952; Applegate, 1961). Differences in the mean lengths and weights of the males and females were statistically significant. The standard error of the difference between the mean lengths was 0.2078;

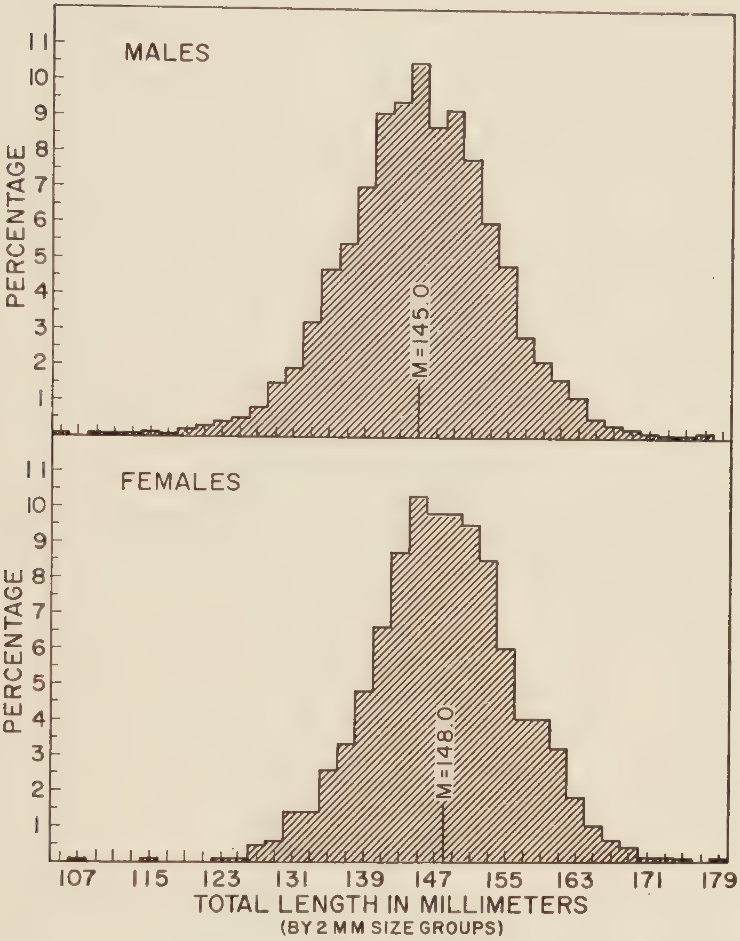

FIG. 6. Percentage frequency of lengths of 6630 recently transformed male and 2052 recently transformed female sea lampreys captured during their downstream migration in the Carp Lake River, Michigan, in 1960–61.

that of the difference between the mean weights was 0.0189. In both, the *t* ratios greatly exceed the 1% level of significance.

To explore further the sex difference in size of recently transformed sea lampreys, we also measured the lengths of 1862 migrants (768 males and 1094 females) collected in the Pere Marquette River in 1962-63. Again the mean length of the males was significantly smaller than that of the females. Total lengths of males in the samples of this run averaged 135.7 mm (S.D. = ±9.8) and ranged from 109 to 170 mm. Females averaged 137.5 mm (S.D. = ±9.4) and varied from 96 to 180 mm. The standard error of the difference between the mean lengths of the males and females was 0.453. The *t* ratio exceeded the 1% level of significance.

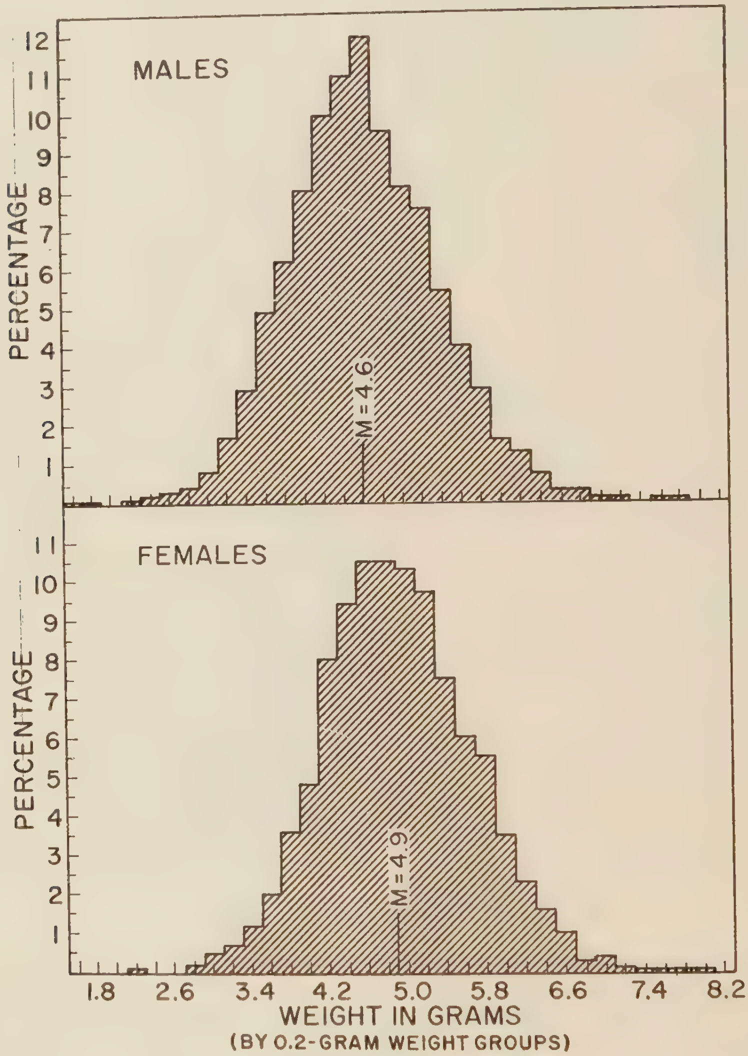

Fig. 7. Percentage frequency of weights of 6630 recently transformed male and 2052 recently transformed female sea lampreys captured during their downstream migration in the Carp Lake River, Michigan, in 1960–61.

Both male and female migrants in the Pere Marquette River averaged approximately 10 mm shorter than those in the Carp Lake River. Substantial variations in the growth of larval lampreys and in the average size of recently transformed downstream migrants in different streams have been reported to us by personnel engaged in sea lamprey control. We presume that these differences in larval growth and size at transformation are the result of varying population densities and suitability of larval habitat in different waters.

## Seasonal Differences in Length and Weight

Applegate (1961) has shown that the size of recently transformed sea lampreys increases progressively during the period of downstream movement. The average total length of both male and female migrants of the 1960–61 downstream run in the Carp Lake River, computed for successive semi-monthly periods, was least in the autumn, increased during the early winter, and was greatest during the late winter and early spring (Table III). A similar, progressive increase in weight was lacking in the lampreys of this run. The average weight for periodic samples of male migrants was least in the early autumn, greatest in the late autumn and early winter, and less again in the late winter

Table III. Average lengths and weights of males and females among recently transformed sea lampreys migrating downstream in the Carp Lake River, Michigan, during semi-monthly periods in the fall, winter, and spring of 1960–61.

| Semi-monthly period (1960–61) | Males | | | Females | | |
|---|---|---|---|---|---|---|
| | Number measured | Average length | Average weight | Number measured | Average length | Average weight |
| | | *mm* | *g* | | *mm* | *g* |
| Sept. 15–30 | 1 | (149) | (5.1) | 0 | – | – |
| Oct. 1–15 | 12 | 138.7 | 3.9 | 0 | – | – |
| 16–31 | 584 | 143.0 | 4.3 | 137 | 146.4 | 4.8 |
| Nov. 1–15 | 3046 | 144.5 | 4.6 | 906 | 147.0 | 4.9 |
| 16–30 | 2295 | 144.5 | 4.6 | 754 | 147.9 | 4.9 |
| Dec. 1–15 | 263 | 145.3 | 4.4 | 83 | 149.0 | 4.8 |
| 16–31 | 45 | 145.7 | 4.2 | 17 | 146.5 | 4.3 |
| Jan. 1–15 | 16 | 145.8[a] | 4.2[a] | 14 | 149.5[a] | 4.9[a] |
| 16–31 | 26 | | | 8 | | |
| Feb. 1–15 | 8 | 143.2[a] | 4.1[a] | 1 | 156.0[a] | 5.1[a] |
| 16–28 | 5 | | | 4 | | |
| Mar. 1–15 | 86 | 147.8 | 4.5 | 40 | 147.9 | 4.7 |
| 16–31 | 222 | 145.2 | 4.2 | 76 | 147.8 | 4.5 |
| Apr. 1–15 | 19 | 146.2[a] | 4.4[a] | 11 | 150.6[a] | 5.0[a] |
| 16–30 | 2 | | | 1 | | |
| Grand totals and averages | 6630 | 145.0 | 4.6 | 2052 | 148.0 | 4.9 |

[a] Averages computed for monthly period because of small number of specimens.

and early spring. Average weights of female migrants varied from period to period but did not display a well-defined trend toward either an increase or a decrease during the run. Among the females captured during the periods of peak migration in November and March, however, the autumn migrants were heavier than those moving downstream in the spring.

It is evident from these data on length and weight that the "condition" of the recently transformed downstream migrants varies during the migratory period. Seasonal changes in "condition," as reflected in variations in the length–weight relation of the migrants, are described in a subsequent section.

## LENGTH–WEIGHT RELATION

The length–weight relation of recently transformed sea lampreys was calculated from the measurements of 8682 migrants from the 1960–61 downstream run in the Carp Lake River. The general length–weight equation, $W = cL^n$, where $W$ = weight, $L$ = length, and $c$ and $n$ are empirically determined constants, was fitted separately to data from 6630 males and 2052 females. All curves were fitted by least squares to mean lengths and weights for 2.0-mm intervals of length.

The logarithmic forms of the length–weight equations are:

$$\textit{Males} \quad \log W = -4.93791 + 2.585 \log L,$$

$$\textit{Females} \quad \log W = -4.44623 + 2.363 \log L,$$

where $W$ = weight in grams, and $L$ = total length in millimeters.

The empirical data for each length interval (including several intervals that were represented by only one or two lampreys) and the curves based on the above equations are shown in Fig. 8 (A) for the males and Fig. 8 (B) for the females. Most of the disagreement between empirical and calculated weights of both males and females was in the largest and smallest size groups which were represented by few specimens. Agreement between empirical and calculated weights of both sexes was generally very good despite differences in the length–weight relation among the lampreys coming downstream in different months of the migration period; these seasonal variations are discussed in the next section.

Comparison of the logarithmic equations describing the length–weight relation of the males and females indicates a difference between the sexes which is not readily apparent in the calculated curves of Fig. 8 (A) and (B). This difference is illustrated best by the logarithmic lines for the sexes as shown in Fig. 8 (C). The weight of recently transformed male sea lampreys increased at a greater rate with increasing length than did that of the females. In the smallest migrants, the females were significantly heavier, length for length, than the males. This sexual difference diminished as the length of the migrants increased and disappeared among the longest individuals. Differences in "form" and "fatness" between the sexes at this stage of the sea lampreys' life cycle.

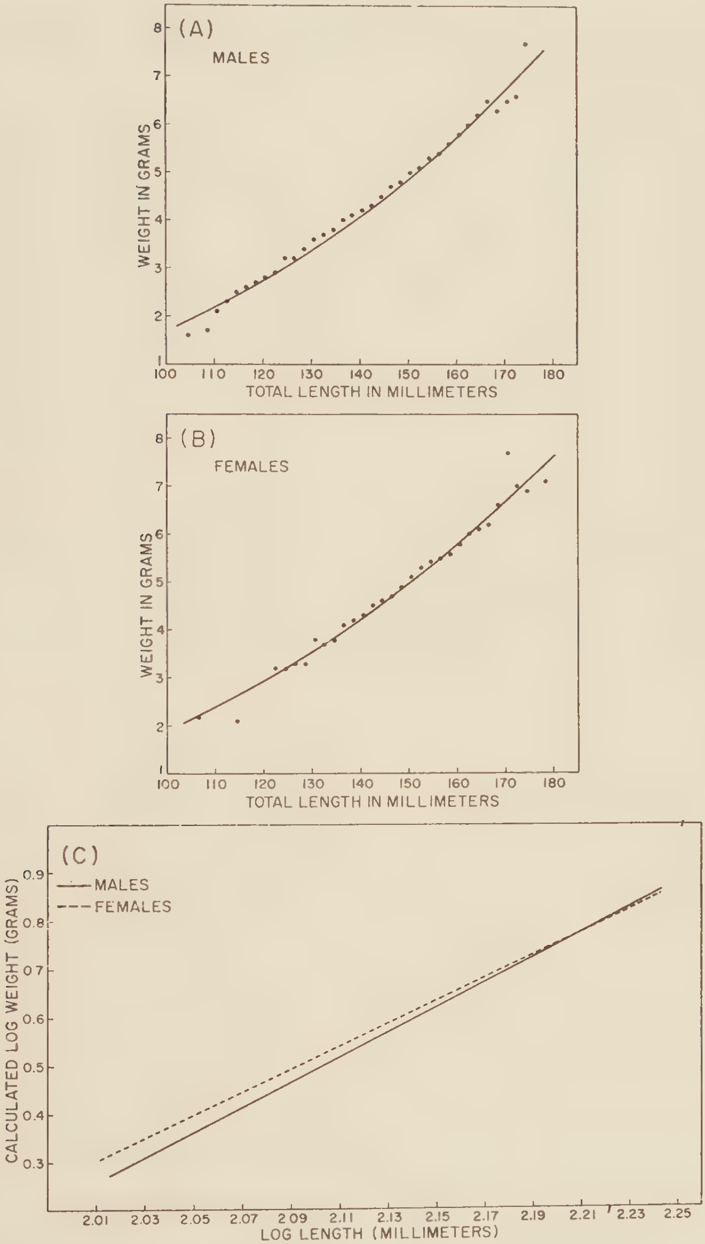

FIG. 8. Length–weight relation of recently transformed sea lampreys of the 1960–61 downstream run in the Carp Lake River. The curves of (A) and (B) represent the calculated weights and the dots, the empirical weights for each length interval. Graph (C) gives the relation for male and female sea lampreys in terms of calculated log weight and log length; empirical weights are omitted from (C).

though not extreme, are still of biological import. The greater weight of the females at nearly all sizes probably reflects an even greater weight advantage at the onset of metamorphosis; the considerable development of the ovary must have taken place at the expense of body tissue.

The mean value of $n$ of about 2.47 for all of the Carp Lake River migrants is exceptionally low for a fish and lower than for other stages of the sea lampreys' life cycle. In adult sea lampreys of several successive spawning runs in a Lake Huron tributary, the value of $n$ varied between 2.9 and 3.0 (Applegate, unpublished data). The length–weight relation of larval sea lampreys from tributaries of the Finger Lakes of New York has been described by Wigley (1959). Although Wigley did not calculate the equation $W = cL^n$, examination of his data shows that the value of $n$ for the larvae would also be close to 3.0. The reason for the less rapid increase of weight with length in the recently transformed migrants than in earlier and later stages of their life is not clear.

### SEASONAL DIFFERENCES IN LENGTH–WEIGHT RELATION

Sufficient specimens were collected during the peaks of downstream movement in October, November, and December 1960 and March 1961 to permit comparisons of the length–weight relation of the lampreys in each of these months. The logarithmic forms of the length–weight equation ($W$ = weight in g; $L$ = length in mm) that describe the relation in male migrants in each of these months are:

$$\begin{array}{ll} \textit{October} & \log W = -4.98697 + 2.605 \log L, \\ \textit{November} & \log W = -4.57705 + 2.424 \log L, \\ \textit{December} & \log W = -4.51058 + 2.383 \log L, \\ \textit{March} & \log W = -4.75917 + 2.489 \log L. \end{array}$$

The corresponding equations for females are:

$$\begin{array}{ll} \textit{October} & \log W = -4.02751 + 2.175 \log L, \\ \textit{November} & \log W = -4.51073 + 2.395 \log L, \\ \textit{December} & \log W = -4.41501 + 2.341 \log L, \\ \textit{March} & \log W = -5.56958 + 2.871 \log L. \end{array}$$

Graphs of the logarithmic lines are shown in Fig. 9 (A) for the males and Fig. 9 (B) for the females (empirical data on the weight at each length are omitted to simplify comparisons of the lines).

Month-to-month differences in the rate of increase of weight of male lampreys with increase in length and in the actual weight did occur but did not follow a consistent seasonal trend. Weight increased most rapidly in October, least rapidly in December, and at intermediate rates between these

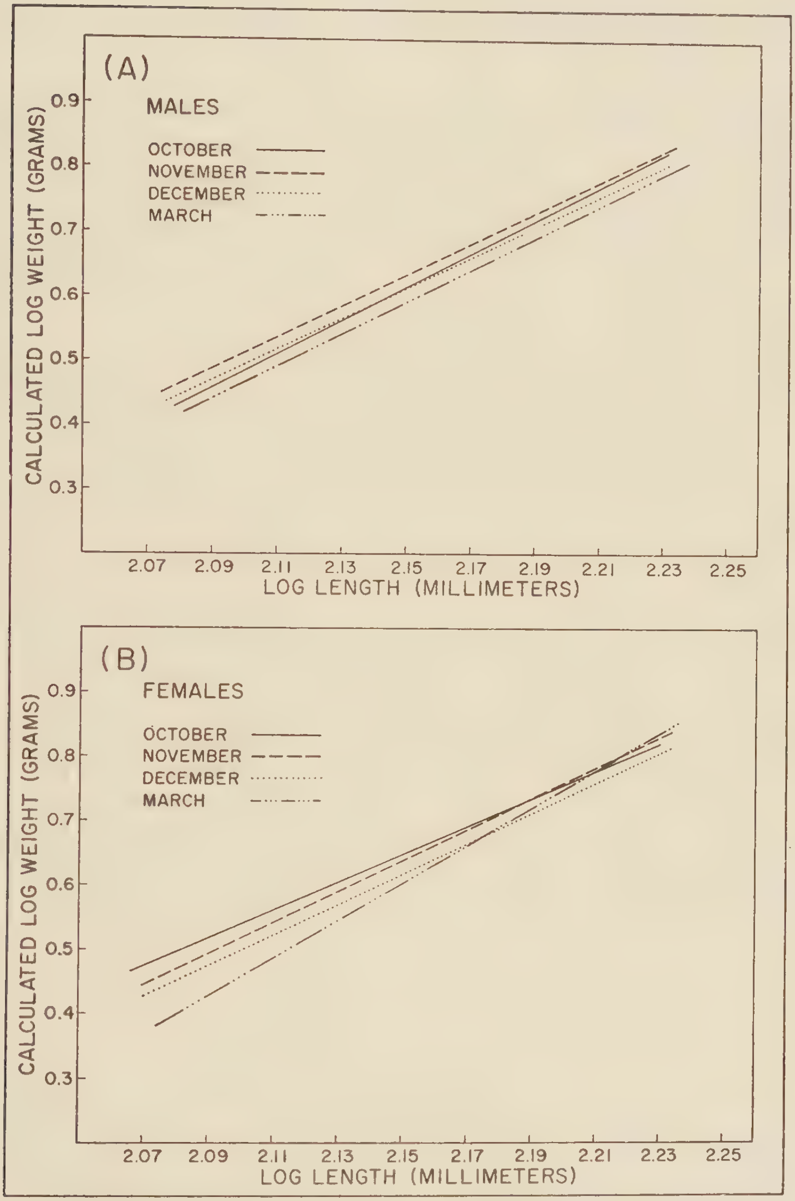

FIG. 9. Seasonal changes in the length–weight relation of recently transformed sea lampreys of the 1960–61 downstream run in the Carp Lake River. Data presented as calculated log of weight in grams and log of length in millimeters. Empirical weights and all length groups that included less than four individuals omitted from these graphs. (A), male sea lampreys; (B), female sea lampreys.

extremes in November and March. At equivalent lengths, the males were heaviest in November, lightest in March, and intermediate in October and December.

The rate of increase of weight of the females with length also changed during the run. Weight increased least rapidly with length in October, most rapidly in March, and at intermediate rates in November and December. Among the smaller individuals, the females were heaviest at equivalent lengths in October and progressively lighter in November, December, and March. As the size of the females increased this progressive loss of weight during the migratory period became less evident. Among the longest females there was little, if any, difference in weight between early migrants in October and late migrants in March.

Seasonal changes in the length–weight relation of the recently transformed downstream migrants can best be summarized as a general progressive loss of weight during this period in which they do not feed. A curious feature of the Carp Lake River migrants, however, was that the males coming downstream in November were significantly fatter than those migrating in October, although weight did decrease in subsequent months. Weights of females did not follow a similar trend. We cannot explain the increased weight of the males in November. We might understand better if we knew the history of these lampreys prior to migration. Metamorphosis usually starts in late summer and is complete by the time the lampreys migrate downstream. Individuals destined to transform in a given season, however, do not do so in a brief period nor do they migrate at the same time. It is possible that the November male migrants were from a local population of relatively heavy ammocoetes that had enjoyed a better-than-average food supply. They might also represent an aggregation of ammocoetes that continued to feed somewhat longer than did those that produced the lampreys moving downstream in October. Lower weights of migrants in the winter and spring is to be expected because of the lengthening period during which the transforming and transformed individuals have been without food.

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## REFERENCES

Applegate, Vernon C. 1950. Natural history of the sea lamprey, *Petromyzon marinus*, in Michigan. *U. S. Fish Wildlife Serv., Spec. Sci. Rept., Fisheries*, No. 55, pp. 1–237.

1961. Downstream movement of lampreys and fishes in the Carp Lake River, Michigan. *Ibid.*, No. 387, pp. 1–71.

Applegate, Vernon C., and Clifford L. Brynildson. 1952. Downstream movement of recently transformed sea lampreys, *Petromyzon marinus*, in the Carp Lake River, Michigan. *Trans. Amer. Fish. Soc.*, **81**(1951): 275–290.

Applegate, Vernon C., and Bernard R. Smith. 1951. Sea lamprey spawning runs in the Great Lakes in 1950. *U. S. Fish Wildlife Serv., Spec. Sci. Rept., Fisheries*, No. 61, pp. 1–49.

Applegate, Vernon C., Bernard R. Smith, A. L. McLain, and Matt Patterson. 1952. Sea lamprey spawning runs in the Great Lakes in 1951. *U. S. Fish Wildlife Serv., Spec. Sci. Rept., Fisheries*, No. 68, pp. 1–37.

Erkkila, Leo F., Bernard R. Smith, and Alberton L. McLain. 1956. Sea lamprey control on the Great Lakes, 1953 and 1954. *U. S. Fish Wildlife Serv., Spec. Sci. Rept. Fisheries*, No. 175, pp. 1–27.

Hardisty, M. W. 1960a. Sex ratio of ammocoetes. *Nature*, **186**(4729): 988–989.

1960b. Development of the gonads in parasitic and non-parasitic lampreys. *Ibid.*, **187**(4734): 341–342.

1961a. Sex composition of lamprey populations. *Ibid.*, **191**(4793): 1116–1117.

1961b. Oocyte numbers as a diagnostic character for the identification of ammocoete species. *Ibid.*, **191**(4794): 1215–1216.

Okkelberg, Peter. 1921. The early history of the germ cells in the brook lamprey, *Entosphemus wilderi* (Gage), up to and including the period of sex differentiation. *J. Morphol.*, **35**(1): 1–127.

Smith, Bernard R., and Alberton L. McLain. 1962. Estimation of the brook and sea lamprey ammocoete populations of three streams. *Great Lakes Fishery Comm., Tech. Rept.* No. 4 (Sept. 1962), pp. 1–18.

Stauffer, Thomas M. MS, 1956. An investigation of the continued capture of downstream-migrating recently transformed sea lampreys in the downstream trap of a weir on Carp Lake River, Emmet County, 1955. *Michigan Institute for Fisheries Research*, Rept. No. 1474, 16 pp.

1962. Duration of larval life of sea lampreys in Carp Lake River, Michigan. *Trans. Amer. Fish. Soc.*, **91**(4): 422–423.

Wigley, Roland L. 1959. Life history of the sea lamprey of Cayuga Lake, New York. *U. S. Fish Wildlife Serv., Fishery Bull.*, No. 154, **59**: 561–617.

Zanandrea, Giuseppe. 1957. Neoteny in a lamprey. *Nature*, **179**(4566): 925–926.

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# TOWING CHARACTERISTICS OF PLANKTON SAMPLING GEAR

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## ABSTRACT

Data on the towing characteristics of the Gulf III, Bary high-speed plankton catcher, Clarke Jet Net, one-meter ring net, Bé multiple plankton sampler, and Isaacs-Kidd midwater trawl, the kite-otter depressor, and Isaacs-Kidd depressor are presented.

The influence of towing speed and cable length on sampling depth was examined. Depth information was telemetered up a single-conductor towing cable from an electronic depth sensor installed between the end of the cable and the device being studied. These data were continuously recorded on deck. Tow paths for each of the devices are illustrated and curves showing the relationship between towing speed, length of cable, and sampling depth are presented for the Gulf III, Jet Net, and Isaacs-Kidd midwater trawl.

## INTRODUCTION

Increasing concern in obtaining quantitative plankton samples has led to the development of various types of opening and closing plankton sampling equipment, flow meters, and high speed samplers, but there are few publications on the towing behavior of sampling devices. The importance of such information was indicated in a study by Aron et al. (1964). They presented data on the towing characteristics of an Isaacs-Kidd midwater trawl (IKMT) and a 1-m ring net. Their study showed that small changes in ship's speed, especially in the range at which most samplers are towed, 3.7 to 11.1 km/hr (2 to 6 knots), produced relatively large changes in the sampling depth. The paper also described in detail the path of the IKMT during deployment, towing, and recovery and showed that changes in technique could introduce considerable differences in the interpretation of the vertical distribution of animals.

The current study presents results of tests made with the 1-m ring net, Gulf III, Bary high-speed plankton catcher, Bé multiple plankton sampler, and the Clarke Jet Net, as well as the kite-otter and Isaacs-Kidd depressors. Data are also presented on the relationship between speed and sampling depth for the IKMT at various lengths of towing cable.

The study was carried out in conjunction with the National Academy of Sciences Committee on Oceanography's (NASCO) Zooplankton Working Group of the Biological Methods Panel (National Academy of Sciences–National Research Council 1964). Fieldwork was conducted off southern California aboard the GM Defense Research Laboratories' *RV Swan*. Except for the IKMT tows, those with the Clarke Jet Net, and the 1-m ring net, made during testing and evaluating the discrete depth plankton sampler system (Aron et al. 1964), the data were obtained on two cruises, 11–13 Nov 1963 and 3–4 Feb 1964, as part of the NASCO Working Group program.

The authors are pleased to acknowledge the assistance provided by the ship's crew and wish to thank Robert Clutter, Robert Counts, Donald Day, David Kramer, and

TABLE 1. *Collection data cruise 11–13 Nov 1963*

| Device | Collection No.-ONR | Speed km/hr | Speed knots | Wire out (m) | Depth (m) | Remarks |
|---|---|---|---|---|---|---|
| Gulf III | 1 | 7.4 | 4 | 201 | 60 | 20 cm nose, 1 mm mesh |
| Gulf III | 2 | 7.4–11.1–14.8 | 4–6–8 | 518 | 144–105–88 | 25 cm nose, 1 mm mesh |
| Gulf III | 6 | 7.4 | 4 | 517 | 145 | 20 cm nose, 0.38 mm mesh |
| Gulf III | 7 | 7.4–11.1–14.8 | 4–6–8 | 511 | 140–99–84 | 20 cm nose, 0.38 mm mesh |
| Gulf III | 8 | 7.4–11.1–14.8 | 4–6–8 | 592 | 143–113–91 | 25 cm nose, 1 mm mesh |
| Jet Net | 3 | 11.1 | 6 | 596 | 118 | Isaacs-Kidd |
| Jet Net | 9 | 7.4 | 4 | 441 | 119 | Isaacs-Kidd |
| Bé sampler | 4 | 1.8–3.7 | 1–2 | 2,000 | 1,440 | 45 kg weight |
| Bé sampler | 5 | 1.8–3.7 | 1–2 | 2,000 | 1,450 | 45 kg weight |
| Bé sampler | 11 | 1.8–3.7 | 1–2 | 1,740 | 1,520 | 45 kg weight |
| 1-m ring net | 10 | 1.8 | 1 | — | 595 | — |
| IKMT | 12 | 4.6 | abt 2.5 | 1,830 | 590 | — |

Herbert Perkins of the Bureau of Commercial Fisheries, Brooke Farquhar of the Naval Oceanographic Office, Karl Banse of the University of Washington, and James Bercaw, Newell Raxter and Frank Bourbeau of the GM Defense Research Laboratories, for their help during the field program.

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## METHODS

The equipment used during the program is described in the following papers:

*Gulf III*—Gehringer (1952). Nose cones with 20 and 25 cm openings were used (*see also* Bridger 1958).

*Bary high speed plankton catcher*—The unit used was developed from the model described by Bary et al. (1958). Its dimensions are similar to their model, but it is fitted with a tail section of the same diameter as the body (in the earlier model the tail section had a smaller diameter). Although the sampler has an opening and closing valve, in the present trials the valve was locked in the open position.

*Bé multiple plankton sampler*—Bé (1962). The prototype and a single-net sampler with a modified pressure-sensitive release mechanism were tested.

*Clarke Jet Net*—Clarke (1964).

*Isaacs-Kidd midwater trawl*—Aron (1962).

*One-m ring net*—Ahlstrom (1952).

*Kite-otter depressor*—Colton (1959).

*Isaacs-Kidd depressor*—Marine Research Committee (1950).

*Electronic bathythermograph, towing cable, and readout equipment*—Aron et al. (1964).

On the cruise of 11–13 Nov, 12 tows were taken: five with the Gulf III, two with the Jet Net, three with the Bé sampler, and one each with the IKMT and the 1-m ring net. The main objectives were to obtain data on the tow paths of these devices and on the influence of speed on the towing depth of the Gulf III.

On the cruise of 3–4 Feb, five series of tows were made at 3.7 to 16.1 km/hr (2 to 8.7 knots) to evaluate the Gulf III, Bary catcher, and the Clarke Jet Net. During each series, the samplers were towed for the same time at the same depth and speed and in the same area. To reduce errors associated with direction, two successive hauls were made on opposite courses with each device. Thus, a series with the three samplers consisted of six tows, resulting in a total of 30 samples.

During the first runs, the samplers were towed at 40 m for 15 min. In later tows, the depth was increased to 50 m to reduce the phytoplankton catch, and the time at depth was shortened to 10 min. The Bary, Clarke, and Gulf III samplers all used nets having approximately 17 meshes/cm with

TABLE 2. *Collection data cruise 3–4 Feb 1964*

| Device | Collection No.-ONR | Speed |  | Wire out (m) | Depth (m) | Depressor |
|---|---|---|---|---|---|---|
|  |  | km/hr | knots |  |  |  |
| Gulf III | 13 | 3.7 | 2 | 125–75 | 50–39 | Isaacs-Kidd |
| Gulf III | 14 | 3.7 | 2 | 80 | 41 | Isaacs-Kidd |
| Gulf III | 19 | 4.1 | 2.2 | 77 | 45–42 | Isaacs-Kidd |
| Gulf III | 20 | 5.6 | 3.0 | 107 | 44 | Isaacs-Kidd |
| Bary net | 15 | 3.7 | 2 | 68–44 | 47–36 | Kite-otter |
| Bary net | 16 | 3.7 | 2 | 43 | 42 | Kite-otter |
| Jet Net | 17 | 3.7 | 2 | 73 | 37 | Isaacs-Kidd |
| Jet Net | 18 | 3.7 | 2 | 91–80 | 48–36 | Isaacs-Kidd |
| Gulf III | 21 | 10.2 | 5.5 | 206 | 50 | Isaacs-Kidd |
| Gulf III | 22 | 10.2 | 5.5 | 210 | 50 | Isaacs-Kidd |
| Bary net | 23 | 10.2 | 5.5 | 124–92 | 60–55 | Kite-otter |
| Bary net | 24 | 10.2 | 5.5 | 82 | 47 | Kite-otter |
| Jet Net | 25 | 10.2 | 5.5 | 194 | 49 | Isaacs-Kidd |
| Jet Net | 26 | 10.4 | 5.6 | 231 | 50 | Isaacs-Kidd |
| Gulf III | 29 | 15.8–16.1 | 8.5–8.7 | 335 | 54–53 | Isaacs-Kidd |
| Gulf III | 30 | 15.2 | 8.2 | 352 | 52 | Isaacs-Kidd |
| Bary net | 31 | 15.0–12.0 | 8.1–6.5 | 132 | 51–54 | Kite-otter |
| Bary net | 32 | 12.0 | 6.5 | 137–104 | 60–55 | Kite-otter |
| Jet Net | 27 | 15.2 | 8.2 | 330 | 49 | Isaacs-Kidd |
| Jet Net | 28 | 15.2–15.9 | 8.2–8.6 | 298 | 52–43 | Isaacs-Kidd |
| Gulf III | 35 | 10.2 | 5.5 | 232 | 54 | Isaacs-Kidd |
| Gulf III | 36 | 10.2–9.6 | 5.5–5.2 | 217 | 50 | Isaacs-Kidd |
| Bary net | 33 | 11.1–11.5 | 6.0–6.2 | 86 | 50–43 | Kite-otter |
| Bary net | 34 | 10.4 | 5.6 | 203 | 52 | Isaacs-Kidd |
| Jet Net | 37 | 9.3 | 5.0 | 222 | 50 | Isaacs-Kidd |
| Jet Net | 38 | 10.4 | 5.6 | 218 | 48 | Isaacs-Kidd |
| Gulf III | 41 | 14.8 | 8.0 | 349 | 52 | Isaacs-Kidd |
| Gulf III | 42 | 15.9 | 8.6 | 350 | 50 | Isaacs-Kidd |
| Bary net | 43 | 15.9 | 8.6 | 279 | 46 | Isaacs-Kidd |
| Bary net | 44 | 15.9 | 8.6 | 272 | 49 | Isaacs-Kidd |
| Jet Net | 39 | 15.9 | 8.6 | 349 | 48 | Isaacs-Kidd |
| Jet Net | 40 | 15.8 | 8.5 | 372 | 52 | Isaacs-Kidd |
| Bary depressor test | 45 | 5.6–14.1 | 3.0–7.6 | 82 | — | Kite-otter |

square apertures of 0.46-, 0.44-, and 0.38-mm side lengths respectively.

Three additional tows, two with the Gulf III using a net with coarser mesh (aperture 1.0 mm square) and one with the Bary sampler to test the stability of the kite-otter depressor, were also made.

Except during one haul with the Bé sampler, depths and temperatures were telemetered via the towing cable to recorders on deck. The electronic bathythermograph used as the sensor was housed in the spreader bar of the IKMT. When used with other samplers, the spreader bar served as a connecting link between the end of the towing cable and the device being tested. For nearly all tows, a pressure transducer with a range from 0–600 m was used; however, for several deep tows (Table 1) a unit with a 0–3,400 m range was installed. Accuracy for both transducers is better than ± 1.5% of full scale. Ship's speed was obtained using a pitometer which is accurate to approximately 0.9 km/hr (0.5 knots).

## FIELD OBSERVATIONS

Data for each of the hauls taken during the two NASCO cruises are given in Tables 1 and 2.

### *The Gulf III*

Two towing methods were used with the Gulf III equipped with the Isaacs-Kidd de-

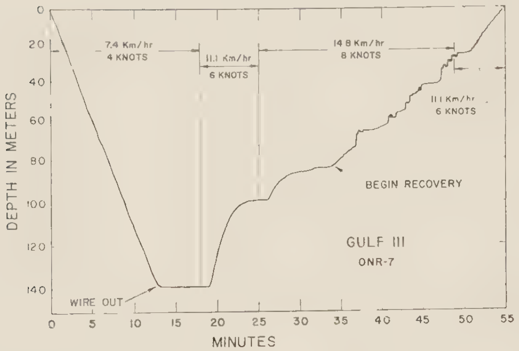

FIG. 1. Multispeed tow with the Gulf III.

pressor. In the first, the gear was deployed with the ship traveling at 7.4 km/hr (4 knots). When the desired depth was reached (about 140 m) the winch was stopped and the ship's speed was increased to 11.1 km/hr (6 knots). This speed was maintained until the sampler reached the new depth, when the speed was again increased to 14.8 km/hr (8 knots). After the gear had reached depth at this speed, it was recovered. For one of these tows (Fig. 1), the Gulf III had a 20-cm nose cone and a net with a mesh opening of 0.38 mm. The other tows of this type, although taken with the sampler using a 25-cm nose cone and a net with a mesh opening of 1.00 mm, were similar, except for differences in detail.

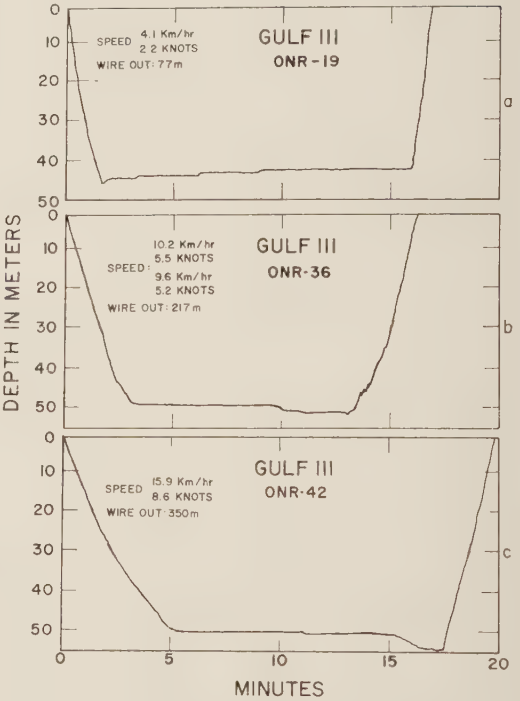

FIG. 2. Constant speed tows of the Gulf III (for ONR-42 the ship speed was reduced at 15 min to permit recovery of the sampler).

In the second method, used mainly for comparing encased (high-speed) samplers, the Gulf III was towed at a constant speed from deployment to recovery. Fourteen of these tows were made at various speeds.

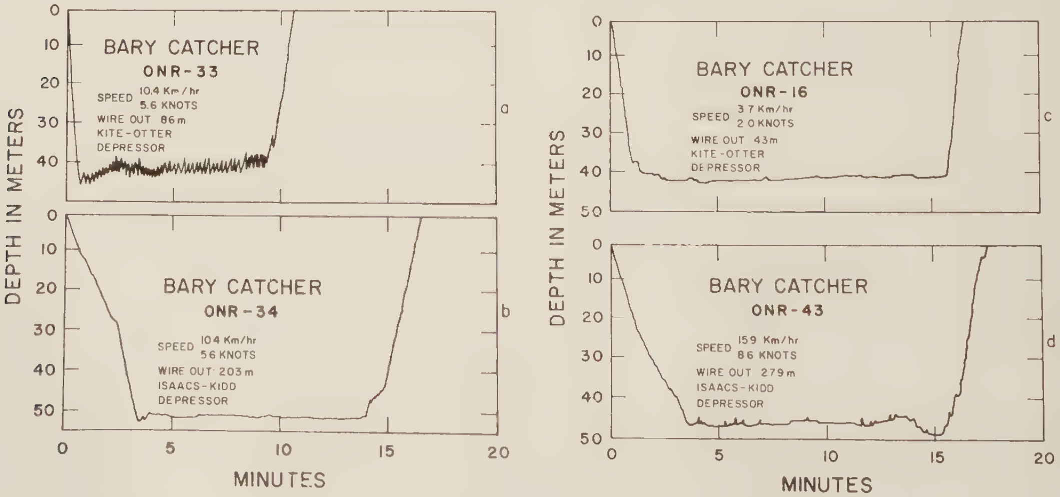

FIG. 3. Constant speed tows of the Bary high-speed sampler.

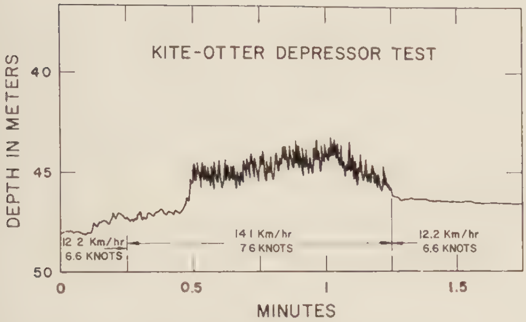

Fig. 4. Bary high-speed plankton catcher, the kite-otter stability test.

Typical depth curves are shown in Figs. 2a, b, and c.

### *The Bary high-speed plankton catcher*

The Bary catcher was available for the second of the NASCO cruises. A kite-otter depressor was used initially with this sampler, but considerable instability of the gear was noted when the ship's speed exceeded 9.3 km/hr (5.0 knots). To determine whether this was caused by the kite-otter depressor, the Isaacs-Kidd depressor, already shown to be stable, was substituted. Figs. 3a and b present depth records from successive tows. The kite-otter depressor was used during tow 33 (Fig. 3a) and the Isaacs-Kidd depressor was used during tow 34 (Fig. 3b). Figs. 3c and d present records from tows made at 3.7 km/hr (2 knots) using the kite-otter, and 15.9 km/hr (8.6 knots) using the Isaacs-Kidd depressor.

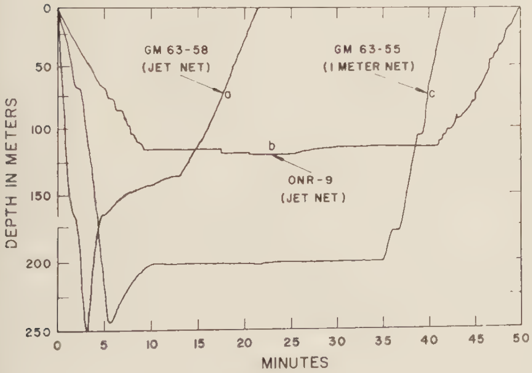

Fig. 5. Constant speed tows of the Clarke Jet Net and 1-m ring net showing the role played by the depressor in determining the path of the sampler.

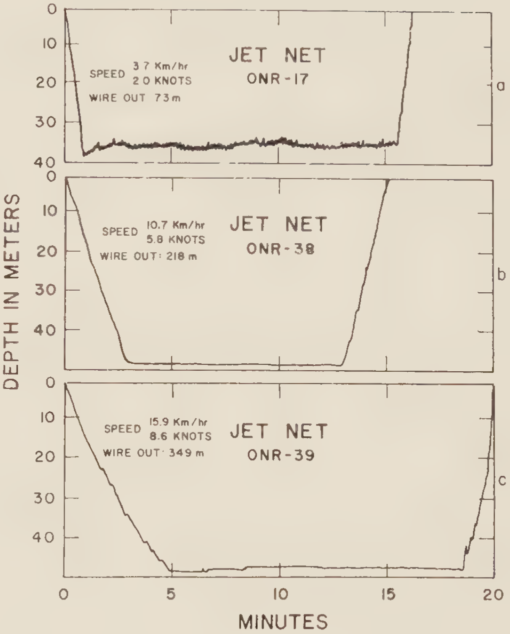

Fig. 6. Constant speed tows of the Clarke Jet Net.

The lengths of the bridles on the kite-otter depressor were adjusted and a test was made to determine the effect of this change on its stability. Fig. 4 is a record of part of the tow.

### *The Clarke Jet Net*

During preliminary trials of the Jet Net, an 82-kg weight was used to attain depth, but in later tests an Isaacs-Kidd depressor was substituted. In Fig. 5, two of the three paths illustrated were followed with this sampler being towed at the same speed, using approximately equal lengths of cable out. In one tow (curve *a*) the 82-kg weight was used and the other (curve *b*) used the Isaacs-Kidd depressor. Data from representative tows made during the second NASCO cruise with the Isaacs-Kidd depressor are given in Figs. 6a, b, and c. Some instability is apparent at 3.7 km/hr (2 knots) but not at higher towing speeds.

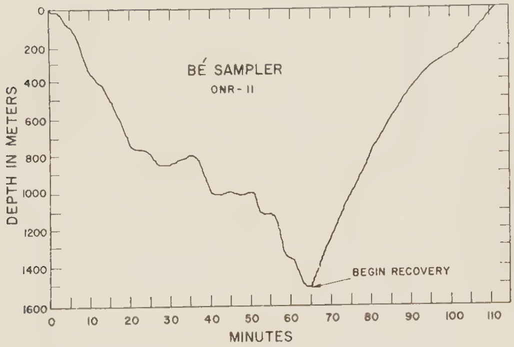

FIG. 7. An oblique tow with the Bé multiple plankton sampler.

### *One-meter ring net*

During a test before the NASCO cruise, a horizontal tow using the 1-m ring net with a 45-kg weight was made at a speed of 3.7 km/hr (2 knots). The technique of lowering and hauling was similar to that used for the Jet Net mentioned above. The tow path is illustrated in Fig. 5 (curve *c*). The single tow with the 1-m ring net taken during the NASCO cruise followed a path similar to the multidepth runs illustrated by Aron et al. (1964).

### *Bé sampler*

The complete tow path of one of the three tows taken with the Bé sampler was recorded (Fig. 7). A single-net sampler was used with the pressure release mechanism set to open the net at a selected depth during descent and to close the net again when the same depth was reached during recovery. A 45-kg weight was used to attain depth.

During deployment the cable was paid out at 18 m/min; recovery was at 27 m/min. In an attempt to maintain an oblique tow, ship's speed was maintained at approximately 1.8 km/hr (1 knot) by applying power intermittently to the propellers.

### *Isaacs-Kidd midwater trawl*

In Fig. 8, the sampling depth of the IKMT has been plotted against towing speed for five different lengths of towing cable. The depth was recorded after the trawl had attained its final depth.

## DISCUSSION

The above results and earlier data (Aron et al. 1964) suggest that existing equipment is not always used to maximum advantage and that rigidly standardized procedures are necessary to ensure consistent sampling.

The towing paths of the multispeed tows with the Gulf III sampler are similar to those reported for the IKMT by Aron et al. 1964. Increasing the towing speed of the Gulf III while keeping the cable length constant diminishes its sampling depth, and changes in sampling depth are greater for equivalent changes in speed at low towing speeds than at high speeds. Thus, at 7.4 km/hr (4 knots) the Gulf III sampler reached a depth of 140 m (Fig. 1). In 3 tows of the type illustrated, increasing the towing speed from 7.4 to 11.1 km/hr (4 to 6 knots) diminished sampling depth by 39, 41, and 30 m, but a change from 11.1 to 14.8 km/hr (6 to 8 knots) diminished it by only 17, 15, and 24 m. Because of this, as the speed increased it was necessary to use more cable to maintain the same sampling depth for all of the high speed samplers. During the second NASCO cruise, for example, one tow made with the Jet Net at 3.7 km/hr (2.0 knots) (Fig. 6a) attained a depth of 48 m with 91 m of cable. To reach this depth with the same sampler

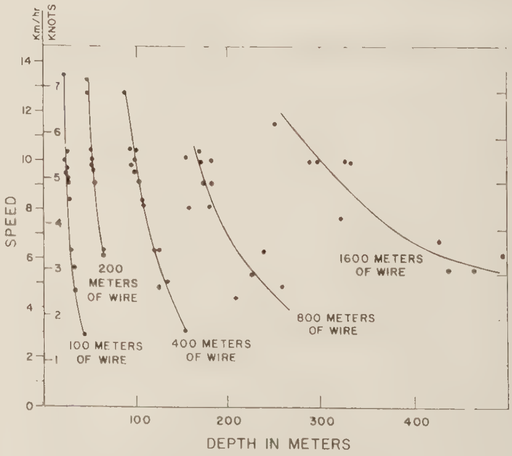

FIG. 8. Sampling depth of the Isaacs-Kidd midwater trawl as a function of towing speed and length of towing cable.

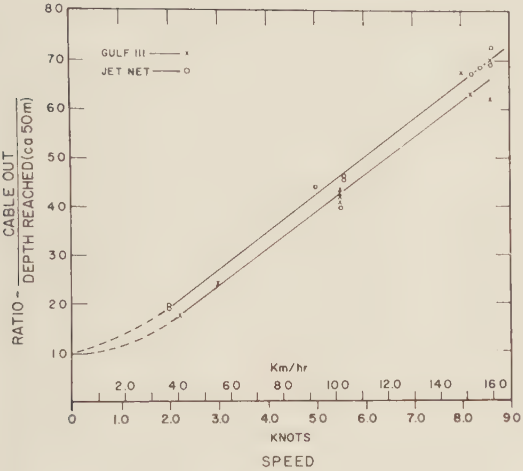

Fig. 9. The ratio of wire out-to-depth reached as a function of towing speed for the Gulf III and Clarke Jet Net towed at about 50 m.

at 15.9 km/hr (8.6 knots) (Fig. 6c) required 349 m of cable.

The relationship between speed of towing and the amount of cable required to reach 50 m with the Gulf III and the Jet Net is shown in Fig. 9, from which the amount of cable needed to reach 50 m at different speeds can be determined. While towing the Gulf III at 7.4 km/hr (4 knots), for example, the length is 3.15 (read from Fig. 9) × 50 or 158 m, at 13.0 km/hr (7 knots) the length is 5.40 × 50 or 270 m, and so on. These curves in Fig. 9 apply only to one depth, speed range, and type of cable. At other depths, with larger diameter cables (the cable used during this program had an outside diameter of 11.18 mm), or at higher towing speeds, the ratio between amount of cable and the depth reached should increase because of the increased lift on the cable; this is indicated in Table 3, which gives data on tows with the Gulf III sampler equipped with a 20-cm nose cone. Except for the 84-m portion of haul ONR-7, the ratio of wire out to sampler depth increased with the depth, and in all cases it increased at higher speeds.

With the IKMT (Fig. 8), as towing speeds increased the ratio of wire length to depth reached is greater for the longer than for the shorter lengths of cable, but as the speed is reduced the lift on the wire is also reduced, so that the ratio between the depth reached and cable length was nearly equal for all lengths of cable at low speed.

The three encased nets when used with the Isaacs-Kidd depressor behaved similarly. The Gulf III had the greatest stability at all speeds. It is the largest and heaviest of the samplers (and also the most difficult to handle) and was equipped with an accumulator in the towing bridle. These features probably minimize the effects of ship's movements caused by sea conditions on its towing behavior. The instabilities of the Bary catcher and the Jet Net were probably not due to the design of the samplers themselves. The reduced efficiency of hydrodynamic depressors at low speeds may have contributed to the irregular tow path of the Jet Net at 3.7 km/hr (2.0 knots), and the instability of the kite-otter depressor at high speeds undoubtedly caused the erratic towing behavior of the Bary catcher. Furthermore, it has been shown that the Jet Net is stable when towed with simple lead weights rather than depressors; this technique has not been tried with the Bary catcher.

The kite-otter depressor required considerably less towing cable (on the order of one-half) at the speeds and depths tested than did the Isaacs-Kidd depressor (Table 2). The inconvenience of handling the kite-otter depressor (it weighs 35 kg compared with the 20 kg weight of the Isaacs-Kidd depressor) is offset by its greater efficiency. If the instability of the kite-otter depressor (Figs. 3a and 4) should prove to be a consistent feature, it would present a serious limitation on its wider use. This

Table 3. *Ratios of cable out/depth reached for different depths and towing speeds for the Gulf III sampler*

| Source of data | Depth reached (m) | Ratio cable out/depth reached | | |
|---|---|---|---|---|
| | | 7.4 km/hr (4 knots) | 11.1 km/hr (6 knots) | 14.8 km/hr (8 knots) |
| Fig. 9 | 50 | 3.15 | 4.65 | 6.20 |
| ONR 1 | 60 | 3.35 | — | — |
| ONR 6 | 145 | 3.57 | — | — |
| ONR 7 | 146–99–84 | 3.65 | 5.16 | 6.08 |

limitation is exaggerated because the instability was not indicated by variations in the wire angle or towing tension, once the equipment reached depth. However, the stability could be increased by a slight adjustment of the bridles, suggesting a solution to the problem that might make the kite-otter depressor most useful.

Another function of the depressors is indicated in Fig. 5. In the two tows in which lead weights were used (curves *a*, *c*), there was a substantial decrease in depth of the sampler when the brake on the winch was applied. For the Jet Net, at 7.4 km/hr (4 knots) (using an 82-kg weight) this change was 110 m, and about 10 min elapsed before the final towing depth was reached (Fig. 5a). For the 1-m ring net, at 3.7 km/hr (2 knots) (using a 45-kg weight) the depth changed 45 m in 5 min (Fig. 5c). In the comparable tow with the Jet Net, using the Isaacs-Kidd depressor, the initial sampling depth was maintained. The final depth reached for approximately equal lengths of cable was almost the same in the two tows (Figs. 5a and b) with the Jet Net (using weight and depressor), even though the Isaacs-Kidd depressor weighs only 20 kg. These differences are attributed to the hydrodynamic efficiency of the depressor with its rapid response to changes in speed.

The tow path with the Bé sampler (Fig. 7) was irregular, except during recovery, in spite of efforts to obtain a linear, oblique tow by controlling ship and winch speeds. For example, during the 8 min elapsing 29 min after the net entered the water, there was a slight decrease in sampling depth, but during the following 5 min, the net descended about 200 m. Similar, but smaller, excursions can be seen to the end of the descent. During the recovery, the tow path was essentially oblique.

The variations in the effects of weights and depressors dictate caution in their selection and use. The Jet Net tows with the 82-kg weight were very different than with the Isaacs-Kidd depressor, although other factors were nearly the same, and samples so taken could differ widely.

High speed plankton samplers will probably be used more and more widely, and reliable and efficient depressors will be required. It is evident that their design and performance must be carefully evaluated. Our experiments also demonstrate the need for the careful maintenance of ship's speeds or the use of depth recorders.

Our results and those of Aron et al. (1964) suggest that some biological variability in collections may actually be an artifact of sampling. Problems associated with variations of time and space among pelagic organisms are already difficult enough to evaluate without imposing additional complexity through the inadequate understanding of the sampling tools.

## REFERENCES

Ahlstrom, E. H. 1952. Pilchard eggs and larvae and other fish larvae, Pacific Coast, 1950. U.S. Fish Wildlife Serv. Spec. Sci. Rept. Fisheries, **80**: 1–58.

Aron, W. 1962. Some aspects of sampling the macroplankton. Rappt. Proces-Verbaux Reunions, Conseil Perm. Intern. Exploration Mer, **153**: 29–38.

———, N. Raxter, W. Andrews, and R. Noel. 1964. A description of a discrete depth plankton sampler with some notes on towing behavior of a 6-foot Isaacs-Kidd midwater trawl and a one-meter ring net. Limnol. Oceanog., **9**: 324–333.

Bary, B. M., J. G. De Stefano, M. Forsyth, and J. Van Den Kerkhof. 1958. A closing, high-speed plankton catcher for use in vertical and horizontal towing. Pacific Sci., **12**: 46–59.

Bé, A. W. H. 1962. Quantitative multiple opening-and-closing plankton samplers. Deep-Sea Res., **9**: 144–151.

Bridger, J. P. 1958. On efficiency tests made with a modified Gulf III high-speed tow net. J. Conseil, Conseil Perm. Intern. Exploration Mer, **23**: 357–365.

Clarke, W. D. 1964. The Jet Net a new high-speed plankton sampler. J. Marine Res., **22**: 284–287.

Colton, J. B., Jr. 1959. The multiplane kite-otter as a depressor for high-speed plankton samplers. J. Conseil, Conseil Perm. Intern. Exploration Mer, **25**: 29–35.

Gehringer, J. W. 1952. An all-metal plankton sampler (model Gulf III). U.S. Fish Wildlife Serv. Spec. Sci. Rept. Fisheries, **88**: 7–12.

Marine Research Committee. 1950. California Cooperative Sardine Research Program. Progress Report 1950, p. 1–54.

National Academy of Sciences–National Research Council. 1964. Recommended interim procedures for measurements in biological oceanography, p. 1–23.

"ATLANTIC OCEAN"

*By*

Thomas S. Austin

## Atlantic Ocean

In 1963, scientists aboard fourteen vessels from seven nations completed a cooperative, synoptic oceanographic study of waters of the Tropical Atlantic. Designated as the International Cooperative Investigations of the Tropical Atlantic (ICITA), the program consisted of a midwinter (EQUALANT I) and a midsummer (EQUALANT II) physical-chemical oceanographic, marine biological, and meteorological survey in an area from the latitude of the Canary Islands south to that of Ascension Island and from the east coast of South America to the west coast of Africa. A second midwinter survey (EQUALANT III) was subsequently planned and completed.

**Background.** Oceanographers from many nations have been studying the waters of the Tropical Atlantic Ocean for nearly 100 years. Famous research vessels which have worked in this area include: *Challenger* (England, 1873 and 1876); *Blake* (USA, 1879); *Talisman* (France, 1882); *Gauss* (Germany, 1901); *Meteor* (Germany, 1926 and 1938); *Albatross* (Sweden, 1948); *Atlantis* (USA, 1959); and the *Lomonosov* (USSR, 1960).

The total available data collected from over 50 research vessels are insufficient to adequately describe the area. From 20°N to 20°S latitudes, between the coast of South America and Africa, includes an area of over 7,000,000 square miles, which is more than twice that of the continental United States. A total of approximately 2200 oceanographic stations were taken at specified locations between 1900 and 1960. The inadequacy of these data, especially when seasonal variations are taken into consideration, is demonstrated by the fact that for the month of June (all years together) there was an average of one station per 250,000 square nautical miles, and for February, one station per 18,000 square nautical miles. The task of collecting sufficient data is so great that no one nation could attempt to undertake it in one year, even by assigning all, or a major portion, of its qualified marine scientists and research vessels. International cooperation is one means whereby oceanographic studies of large areas may be carried out.

The ICITA evolved from a proposal by the Commission for Technical Cooperation in Africa (CTCA) to make trawling investigations of West African waters from the mouth of the Congo River north to Dakar, Senegal. In 1961, the Bureau of Commercial Fisheries proposed making a study of the pelagic areas of the Gulf of Guinea. Plans and schedules for combining these investigations were formulated by participants in an Intergovernmental Oceanographic Commission (IOC) working group meeting held in Washington, D.C., during June, 1962.

Observational and sampling programs developed by scientists from 16 nations included Nansen bottle casts to a minimal depth of 2000 meters

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(to the bottom every 120 miles) with measurements of temperature, salinity, oxygen, and inorganic phosphate content taken at each depth; bathythermograph (BT) lowerings every 30 miles; daily surface and subsurface measurements of primary productivity using the carbon-14 isotope technique and of microbiomass; a zooplankton tow once each night; and routine meteorological observations. Plans for various special types of observations aboard one or more participating vessels included upper-air meteorological data, sea surface radiation measurements, special cloud observations and photographs, and direct current measurements. These were made by instrumented buoy arrays anchored from the Woods Hole Oceanographic Institution research vessel *Chain* and the Soviet vessel *Lomonosov* and from drogue measurements from the United States Coast and Geodetic Survey ship, *Explorer*.

**Results.** Fourteen vessels of seven nations—Argentina, Brazil, Congo (Brazzaville), Nigeria, Republic of Ivory Coast, United States and the U.S.S.R.—participated during EQUALANT I (February-April, 1963, Figs. 1 (*a*) and 2 (*a*). Eleven vessels from these nations, with the addition of Spain, participated in EQUALANT II (August-September, 1963, Figs. 1 (*b*) and 2 (*b*). Scientists from Germany, United Kingdom, and Venezuela,

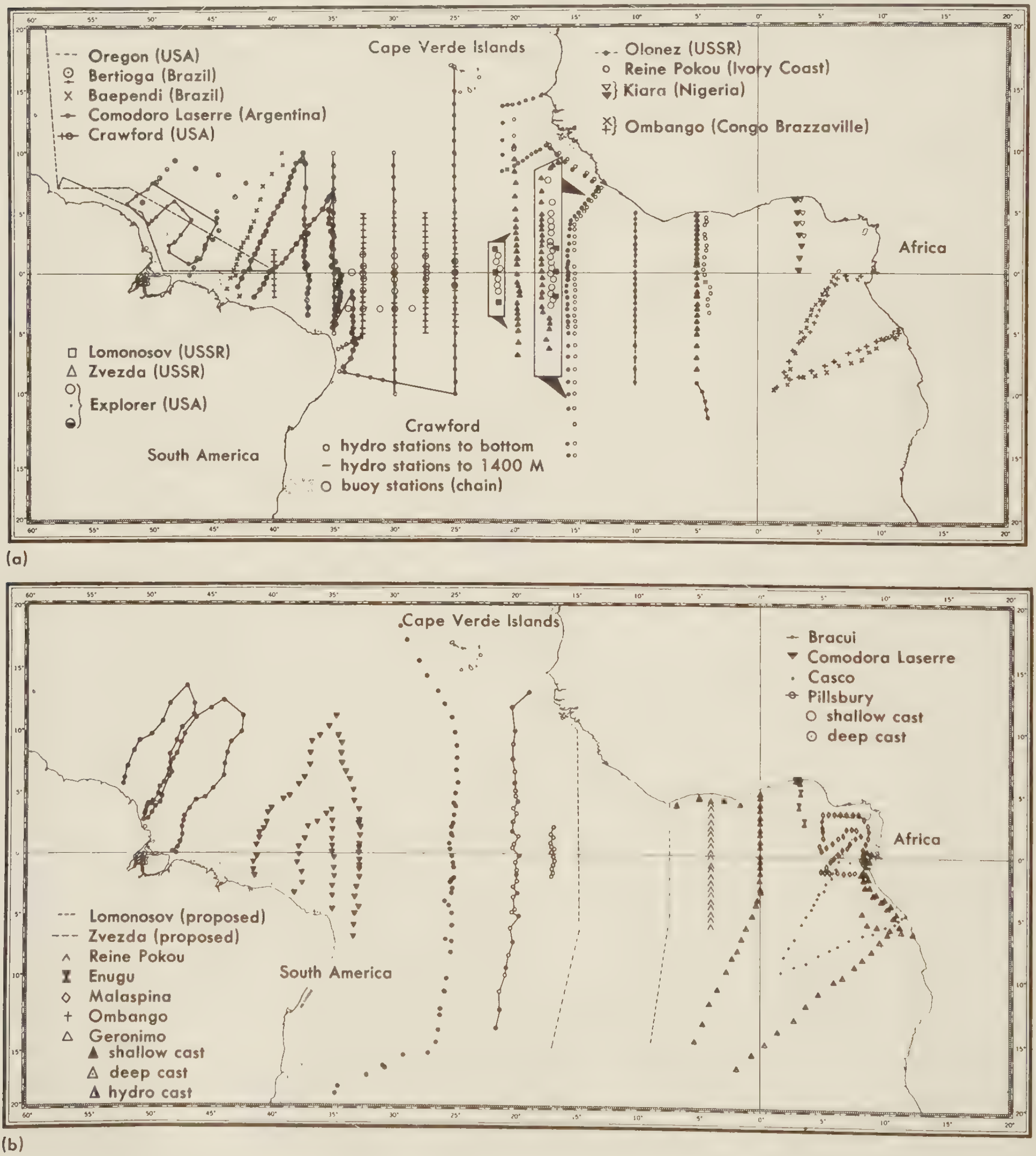
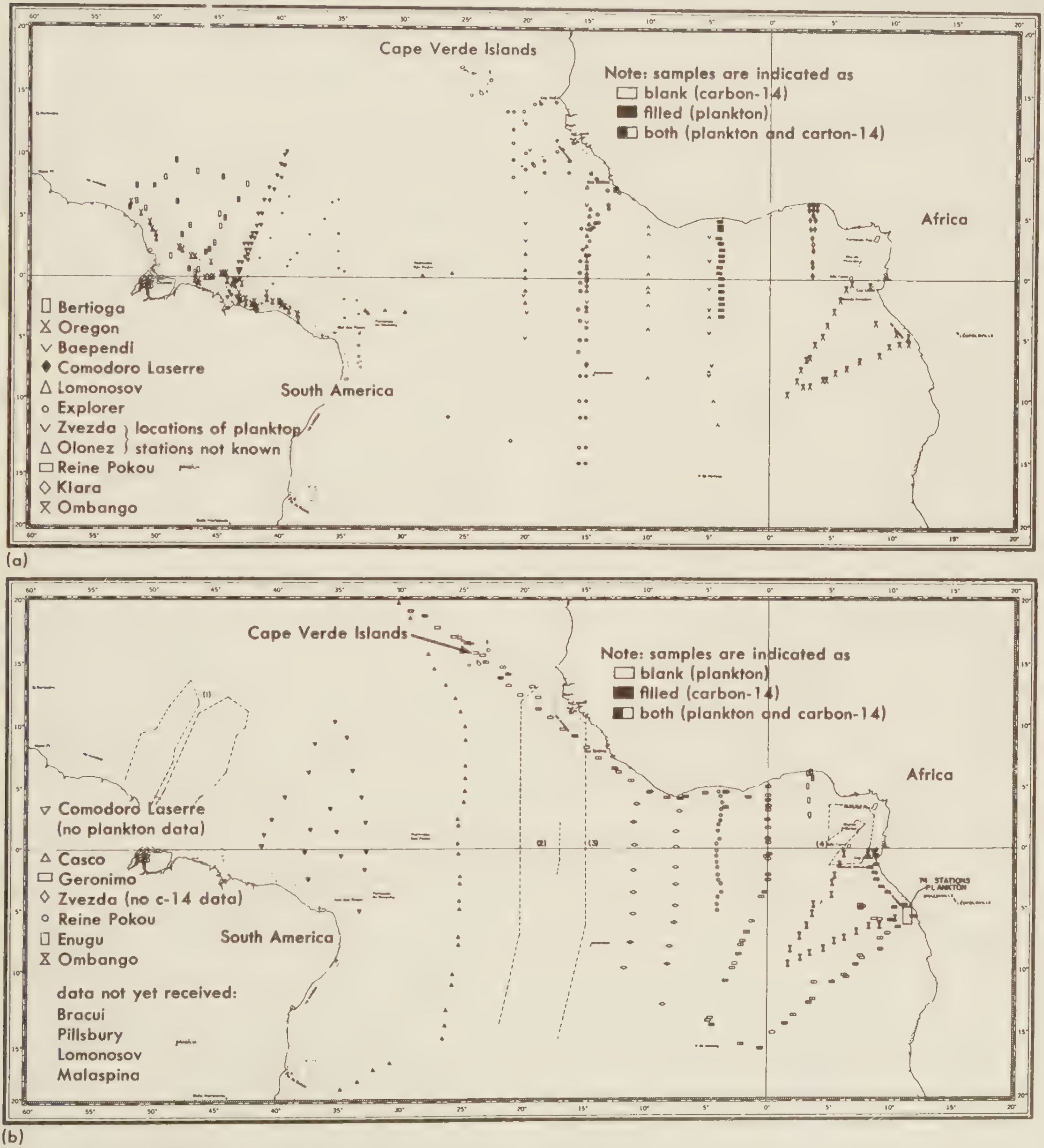

--- Oregon (USA)
Bertioga (Brazil)
× Baependi (Brazil)
Comodoro Laserre (Argentina)
Crawford (USA)
Cape Verde Islands
Olonez (USSR)
o Reine Pokou (Ivory Coast)
Kiara (Nigeria)
Ombango (Congo Brazzaville)
Africa
□ Lomonosov (USSR)
△ Zvezda (USSR)
Explorer (USA)
South America
Crawford
o hydro stations to bottom
– hydro stations to 1400 M
O buoy stations (chain)
(a)
Cape Verde Islands
Bracui
Comodora Laserre
Casco
Pillsbury
O shallow cast
⊙ deep cast
Africa
--- Lomonosov (proposed)
--- Zvezda (proposed)
^ Reine Pokou
Enugu
◇ Malaspina
+ Ombango
△ Geronimo
▲ shallow cast
△ deep cast
Δ hydro cast
South America
(b)

Fig. 1. Positions of oceanographic stations (surface and subsurface physical and chemical observations). (*a*) EQUALANT I; (*b*) EQUALANT II.

as well as from various federal, university, and private organizations of the United States, also participated.

EQUALANT III (February-March 1964) involved work from eight vessels of six nations—Congo (Brazzaville), Ghana, Republic of Ivory Coast, Spain, United States, and U.S.S.R. Direct current measurements were accompanied by a variety of oceanographic and marine biological observations and were made in an area 10°N to 10°S latitudes, 30°W longitude, east to the coast of Africa.

Studies involving three United States satellites, *Tiros-V*, *Tiros-VI*, and *Symcom-II*, were included in the ICITA program. Special cloud observations were made by United States Weather Bureau observers from several of the research vessels. Cloud photographs were obtained from United States Air Force planes flying over the research vessels and, simultaneously, from *Tiros-V* and *VI* Satellites, which were specially programmed to obtain photographic coverage of the EQUALANT area. The cloud photographs from these three sources provided considerable data for studies of the cumulo-nimbus systems and other cloud groups; other evidence of intense convective activity which occurs in the zone of the Inter-Tropical Convergence (ITC); and the characteristics of the Northeast and Southeast Trade Wind zones which lie to the north and south, respec-


Cape Verde Islands
Note: samples are indicated as
blank (carbon-14)
filled (plankton)
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Africa
South America
Bertioga
Oregon
Baependi
Comodoro Laserre
Lomonosov
Explorer
Zvezda
Olonez
locations of plankton stations not known
Reine Pokou
Klara
Ombango
(a)
Cape Verde Islands
Note: samples are indicated as
blank (plankton)
filled (carbon-14)
both (plankton and carbon-14)
Africa
South America
Comodoro Laserre (no plankton data)
Casco
Geronimo
Zvezda (no c-14 data)
Reine Pokou
Enugu
Ombango
data not yet received:
Bracui
Pillsbury
Lomonosov
Malaspina
(1)
(2)
(3)
(4)
(b)

Fig. 2. Positions of biological stations; measurements of primary productivity (surface and subsurface) and zooplankton tows. (a) EQUALANT I; (b) EQUALANT II.

Fig. 3. Bureau of Commercial Fisheries research vessel *Geronimo,* a converted 143-ft Navy seagoing tug.

tively, of the ITC (*see* SPACE PROBES). These characteristics, as yet to be rigorously categorized, reflect the effects of physical processes within each of the major wind systems and appear, to a major degree, to be distinctive features by which these systems may be identified from the *Tiros* photographs.

Temperature and salinity data measured at various depths at a station south of Lagos, Nigeria, were sent via *Syncom-II* Satellite from the Bureau of Commercial Fisheries research vessel *Geronimo* (Fig. 3) to the National Oceanographic Data Center (NODC) in Washington, D.C. These data were subjected to a quality-control analysis at NODC, and a message was transmitted back to the *Geronimo* in less than 30 minutes. Routine use of communication satellites for rapid transmission of oceanographic data will keep scientists aboard research vessels continuously informed as to the quality of their data and will provide for its rapid utilization and dissemination.

Preliminary analyses of ICITA data furnished evidence that an equatorial undercurrent, called the Cromwell Current, is present during both the winter and summer seasons. This subsurface easterly flowing current, centered around the equator (2°N to 2°S latitudes), was first discovered in the Pacific Ocean and, more recently, in the Indian Ocean. *See* INDIAN OCEAN.

The available data suggest that the equatorial undercurrent extends from off the coast of Brazil east into the Gulf of Guinea during the northern winter, but that it may only reach the longitude of Dakar (approximately 15°W) during the summer period.

The undercurrent is characterized by a core of high salinity water (greater than 36 parts per thousand). This core was generally observed at depths of 65–90 meters.

The existence of the undercurrent was confirmed, and the speed and direction measured, by free-floating drogues and by direct-reading current meters. The buoy, from which the drogue was suspended, moved at a speed which caused a clearly evident "wake." This buoy was in the westerly flowing surface current; the drogue in the easterly flowing undercurrent. Speeds of 1–3 knots were recorded for the undercurrent.

Data reports for EQUALANTS I, II, and III are being published by the National Oceanographic Data Center, Washington, D.C.; preparation and publication of atlases describing results of the ICITA are to be coordinated by the Secretariat of the Intergovernmental Oceanographic Commission.

For background information *see* ATLANTIC OCEAN; OCEANOGRAPHY in the McGraw-Hill Encyclopedia of Science and Technology.

[THOMAS S. AUSTIN]

*Bibliography*: Thomas S. Austin, *A.I.B.S. Bull.*, vol. 13, no. 5, 1963, Vernon E. Brock, ICO Pamphlet No. 11, April 1963.

## NOTES AND NEWS

An observation of Laevicardium mortoni actually swimming.—On June 1, 1963, while collecting the ectoparasitic gastropod, *Odostomia bisuturalis* (Say, 1821), on its host the common oyster, *Crassostrea virginica* (Gmelin, 1790), we witnessed an unusual phenomenon in the behavior of a pelecypod. This happening was so unusual that it might have gone unreported for lack of confirmation had only one of us observed the occurrence. We were wading side-by-side in shallow water when we observed what appeared to be a 'tadpole' swimming. Leaning forward, we saw *Laevicardium mortoni* (Conrad, 1830), its foot extended well beyond the ventral edge of the shell and moving in a sculling motion, in this way propelling the shell through the water. In a few moments the animal withdrew its foot and fell to the bottom where it remained on its side. It was then that we identified the species. This observation was made several hundred feet in from the mouth of Bass River, a river which separates the towns of West Dennis and Yarmouth, Massachusetts, on Cape Cod. The tide was ebbing, the water was 3-6 inches deep, clear, with no ripples to distort the observation. Edward S. Morse (Proc. Bos. Soc. Nat. Hist. *35* (5): 173, 1919) illustrated the extended foot of *L. mortoni* and remarked that, "The foot is long, white and pointed and active in its movements." Morse also mentioned that this animal was able to push itself about with the aid of its foot but so far as we know ours is the first observation of actual swimming movements in this bivalve.—Emmett B. Baker, Kingston, Massachusetts, and Arthur S. Merrill, Woods Hole, Massachusetts.

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# EUTROPHICATION OF THE ST. LAWRENCE GREAT LAKES

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# EUTROPHICATION OF THE ST. LAWRENCE GREAT LAKES[1]

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## ABSTRACT

Lakes Huron, Michigan, and Superior are classified as oligotrophic lakes on the basis of their biological, chemical, and physical characteristics. Lake Ontario, although rich in nutrients, is morphometrically oligotrophic or mesotrophic because of its large area of deep water. Lake Erie, the most productive of the lakes and the shallowest, is eutrophic. Several changes commonly associated with eutrophication in small lakes have been observed in the Great Lakes. These changes apparently reflect accelerated eutrophication in the Great Lakes due to man's activity. Chemical data compiled from a number of sources, dating as early as 1854, indicate a progressive increase in the concentrations of various major ions and total dissolved solids in all of the lakes except Lake Superior. The plankton has changed somewhat in Lake Michigan and the plankton, benthos, and fish populations of Lake Erie are greatly different today from those of the past. An extensive area of hypolimnetic water of Lake Erie has developed low dissolved oxygen concentrations in late summer within recent years.

## INTRODUCTION

Evidence of appreciable change in the biota and physicochemical conditions in Lake Erie (Beeton 1961) and speculation on possible changes in the other lakes, stemming from increases in total dissolved solids (Ayers 1962; Rawson 1951), have directed attention to eutrophication of the Great Lakes. The question does not concern the existence of eutrophication, because all lakes are aging and there is no reason to believe that the Great Lakes are exceptional. Of greatest consequence is the possibility of detection and perhaps even measurement of the rate of eutrophication of these large lakes. Important also is the effect of mankind on the normal rate of eutrophication.

Accelerated rates of aging due to man's activity have been detected in a number of lakes (Hasler 1947). The classic example is the Untersee of Lake Zürich, which urban effluents have changed from an oligotrophic to an eutrophic lake in a relatively short time. Recently, studies of Lake Washington at Seattle (Edmondson, Anderson, and Peterson 1956), and Fure Lake, Denmark (Berg et al. 1958) have demonstrated that these relatively large lakes are undergoing accelerated eutrophication due to man's influence. None of these lakes, however, is large in comparison with any of the St. Lawrence Great Lakes.

## PRESENT TROPHIC NATURE OF THE GREAT LAKES

The meaning of eutrophication seems to vary according to the special interests of the individual. Limnologists agree that eutrophication is part of the aging of a body of water and implies an increase in the nutrient content of the waters. Most lakes change gradually from a nutrient-poor, oligotrophic, to a nutrient-rich, eutrophic, condition. At this point agreement ends in arguments on lake classification. Although the terms eutrophic, mesotrophic, and oligotrophic are used freely by limnologists and are well established in the literature, it is difficult to determine precisely what is meant by them. Various investigators have attached considerable significance to one or more of the following criteria in classifying lakes: abundance or species of plankton or both; benthic organisms; chemical characteristics; sediment types; distribution of dissolved oxygen; productivity; fish populations; and morphometry and morphology of the lake basin. Lake classification has been closely related to regional limnology and has been developed primarily from observations on small lakes. It is not surprising, then, to find that the Great Lakes do not fit readily into the various classification schemes that have been proposed. Rawson (1955, 1956)

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[1] Presented at the symposium on "Recent trends in ecological research in the Great Lakes," sponsored by the Ecological Society of America, American Association for Advancement of Science meetings, Cleveland, 27 December 1963.

TABLE 1. *Physical and chemical characteristics of the Great Lakes**

| Lake | Mean depth (m) | Transparency (average Secchi disc depth, m) | Total dissolved solids (ppm) | Specific conductance (μmhos at 18C) | Dissolved oxygen |
|---|---|---|---|---|---|
| Oligotrophic | >20 | High | Low: around 100 ppm or less | <200 | High, all depths all year |
| Superior | 148.4 | 10 | 60 | 78.7 | Saturated, all depths |
| Huron | 59.4 | 9.5 | 110 | 168.3 | Saturated, all depths |
| Michigan | 84.1 | 6 | 150 | 225.8 | Near saturation, all depths |
| Eutrophic | <20 | Low | High: >100 | >200 | Depletion in hypolimnion: <70% saturation |
| Ontario | 86.3 | 5.5 | 185 | 272.3 | 50 to 60% saturation in deep water in winter |
| Erie, average for lake | 17.7 | 4.5 | 180 | 241.8 | |
| Central basin | 18.5 | 5.0 | — | — | <10% saturation, hypolimnion |
| Eastern basin | 24.4 | 5.7 | — | — | 40 to 50% saturation, hypolimnion |

* Criteria designating lake types are based primarily on factors considered important by Rawson (1960); specific conductance limits from Dunn (1954); dissolved oxygen criteria, Thienemann (1928). Data from Bureau of Commercial Fisheries except transparency and dissolved oxygen for Lake Ontario (Rodgers 1962).

reviewed the problem of classifying large lakes and considered certain characteristics of the St. Lawrence Great Lakes.

Despite the troublesome problems of lake classification, an attempt should be made to classify the Great Lakes for discussion of their eutrophication and to facilitate comparison with other lakes. A better classification surely is needed since Lake Erie, for example, has been called oligotrophic, mesotrophic, and eutrophic by various investigators over the past 30 years.

### *Physicochemical conditions*

Morphometry, transparency, total dissolved solids, conductivity, and dissolved oxygen content of the water appear to be useful in lake classification. On the basis of these five physical and chemical factors, two of the lakes would be classified as oligotrophic, one as tending toward the mesotrophic, and two as eutrophic. The low specific conductance and total dissolved solids, and the high transparency and dissolved oxygen of Lakes Huron and Superior agree with the commonly accepted characteristics of oligotrophy (Table 1). Lakes Erie and Ontario have the high specific conductance and total dissolved solids and, of special significance, the low concentration of dissolved oxygen in the hypolimnion characteristic of eutrophic lakes. Data were not available on the oxygen content of the hypolimnetic waters of Lake Ontario, but it is even more significant that the deep waters had a low percentage saturation of dissolved oxygen under essentially isothermal conditions. The transparencies of Lakes Erie and Ontario are not especially low in comparison with many small lakes, but in comparison to Lakes Huron and Superior, their average transparencies are indeed low. Lake Michigan falls between the other lakes from the standpoint of specific conductance, total dissolved solids, and transparency. The dissolved oxygen content of Lake Michigan water is near saturation, however, at all depths. On occasion, water in the deeper areas has a saturation between 70 and 80%, but these low values are infrequent.

### *Biological characteristics*

The biological characteristics of all the Great Lakes, except Lake Erie, may place them in the oligotrophic category (Table 2). This classification surely holds for Lakes Huron, Michigan, and Superior, but is uncertain for Lake Ontario, where recent and detailed information is lacking on benthos and plankton. The types of bottom fauna, especially the dominant midge larvae, have been recognized for many years

TABLE 2. *Biological characteristics of the Great Lakes**

| Lake | Bottom fauna and dominant midges | Dominant fishes | Plankton abundance | Dominant phytoplankton† |
|---|---|---|---|---|
| Oligotrophic | *Orthocladius-Tanytarsus* type<br>(*Hydrobaenus-Calopsectra*) | Salmonids | Low | *Asterionella formosa*<br>*Melosira islandica*<br>*Tabellaria fenestrata*<br>*Tabellaria flocculosa*<br>*Dinobryon divergens*<br>*Fragilaria capucina* |
| Superior | *Pontoporeia affinis*<br>*Mysis relicta*<br>*Hydrobaenus* | Salmonids | Very low | *Asterionella formosa*<br>*Dinobryon*<br>*Synedra acus*<br>*Cyclotella*<br>*Tabellaria fenestrata*<br>*Melosira granulata* |
| Huron | *Pontoporeia affinis*‡<br>*Mysis relicta*<br>*Hydrobaenus*<br>*Calopsectra* | Salmonids | Low | *Fragilaria crotonensis*<br>*Tabellaria fenestrata*<br>*Fragilaria construens*<br>*Fragilaria pinnata*<br>*Cyclotella kutzingiana*<br>*Fragilaria capucina* |
| Michigan | *Pontoporeia affinis*§<br>*Mysis relicta*<br>*Hydrobaenus* | Salmonids | Low | *Fragilaria crotonensis*<br>*Melosira islandica*‖<br>*Tabellaria fenestrata*<br>*Asterionella formosa*<br>*Fragilaria capucina* |
| Ontario | *Pontoporeia affinis*<br>*Mysis relicta* | Salmonids, ictalurids, percids | — | — |
| Eutrophic | *Tendipes plumosus* type | Yellow perch, pike, black bass | High | *Microcystis aeruginosa*<br>*Aphanizomenon*<br>*Anabaena* |
| Erie | | | | |
| Central basin | *Tendipes plumosus* | Yellow perch, smelt, freshwater drum | High | *Melosira binderana*<br>*Stephanodiscus*<br>*Cyclotella*<br>*Fragilaria crotonensis* |
| Eastern basin | *Pontoporeia affinis*<br>few *Calopsectra* | Yellow perch, smelt, few salmonids | High | *Microcystis*<br>*Aphanizomenon* |

* Criteria for lake types as follows: tendipedid larvae, Brundin (1958); fish and plankton abundance, Welch (1952); dominant phytoplankton, Rawson (1956).

† Data for Lake Michigan from Bureau of Commercial Fisheries; Lake Superior from Putnam and Olson (1961); Lake Erie from Davis (1962); Lake Huron from Williams (1962).

‡ Data from Teter (1960).

§ Data from Merna (1960).

‖ Refers to *Melosira islandica-ambigua* type.

as good criteria for classifying lakes (Elster 1958); Brundin (1958) held this basis had world-wide application. Lakes Huron, Michigan, and Superior are all of the *Orthocladius-Tanytarsus* (*Hydrobaenus-Calopsectra*) type. *Hydrobaenus* and related genera are the only midges in the deeper parts of these lakes. *Calopsectra* occurs in shallower areas with a variety of other midges. In Lake Erie, *Procladius* and *Tendipes* spp. (*T. plumosus* group) are the dominant midges. *Cryptochironomus* and *Coelotanypus* also are abundant in the western basin. *Calopsectra* and a variety of midge larvae become progressively more abundant toward the eastern end of the lake and only a few *Tendipes* appear in samples from the deep (maximum, 64 m) eastern basin.

The crustaceans, *Mysis relicta* and *Ponto-*

*poreia affinis*, are characteristic of oligotrophic lakes, although they occur in lakes classed as mesotrophic. Both organisms require fairly high dissolved oxygen concentrations and cold water. Consequently, they are absent from highly eutrophic lakes. Both crustaceans are found in all of the Great Lakes, but in Lake Erie the major population is restricted to the eastern basin.

Oligotrophic lakes of the north have been considered salmonid lakes. It is not implied that salmonids do not occur in eutrophic lakes, but, when present, they are not the dominant fishes and usually they have a restricted bathymetric distribution. Salmonids dominate the fish populations in all of the lakes except Lake Erie, although in Lake Ontario ictalurids and percids are almost as important in the commercial fishery as salmonids (Table 2). Three native species (formerly four) of salmonids occur in Lake Erie, but during most of the year they are restricted to the eastern basin. Warmwater fishes dominate the fish fauna of Lake Erie now, including the eastern basin.

Considerable controversy exists over the value of plankton in lake classification. Rawson (1956) pointed out that the number of species present, as well as the ecological dominants, should be considered in characterizing plankton. He stressed that the dominant species of plankters in the oligotrophic lakes of Canada, as well as the Great Lakes, were not the species usually associated with oligotrophic lakes. Furthermore, a number of plankters commonly accepted as indicative of eutrophy are dominant species in these lakes. These observations are supported by the more recent plankton data from the Great Lakes. *Fragilaria crotonensis* is a dominant diatom species in Lakes Huron and Michigan as well as Lake Erie, and *Melosira granulata* is a dominant plankter in Lake Superior. Both species are considered to be indicators of eutrophy by Teiling (1955). On the other hand, plankters that are accepted as indicators of oligotrophy (*Dinobryon, Tabellaria, Cyclotella*) are also dominant in the Great Lakes (Table 2). It is agreed, nevertheless, that the Cyanophyceae, *Aphanizomenon, Anabaena,* and *Microcystis,* which are among the dominant plankters in Lake Erie, are good indicators of eutrophy. Little purpose could be served here, however, by further discussion of the problem of plankton indicators of lake types. Consequently, Rawson's (1956) ranking of algae in order of their occurrence from oligotrophy to eutrophy has been used, in part, in Table 2, since he worked on lakes similar in many ways to the St. Lawrence Great Lakes. On the basis of plankton abundance and the dominant species of phytoplankton, Lakes Huron, Michigan, and Superior would be considered oligotrophic and Lake Erie eutrophic.

The combined biological, chemical, and physical characteristics of Lakes Huron and Superior clearly are those of oligotrophy. The biota and the high dissolved oxygen content of the deep hypolimnetic waters characterize Lake Michigan as oligotrophic but contrariwise, the high content of total dissolved solids indicates a trend toward mesotrophy. Lake Ontario, as a mesotrophic lake, retains the biota of an oligotrophic lake, but the physicochemical characteristics are those of eutrophy. The chemical content of the waters of Lake Ontario is closely similar to that of Lake Erie, since the main inflow to Lake Ontario is from Lake Erie via the Niagara River. The trophic nature of Ontario has been determined to a large extent by the chemical history of Lake Erie waters. Lake Ontario, and perhaps Lake Michigan, would be eutrophic except for the large volumes of deep waters. Even in Lake Erie, the eastern basin has components of a fauna associated with oligotrophy and sufficient deep, cold, oxygenated water to maintain this fauna. These conditions exist despite the highly eutrophic nature of the central basin (flow through the lake is from west to east). The evident ability of the total dissolved oxygen content of the deep hypolimnetic waters to meet the oxygen demand of the organic production of the epilimnetic waters, as well as the oxygen demand of allochthonous materials, makes Lakes Michigan, Ontario, and eastern Lake Erie in some measure oligotrophic (or mesotrophic) because of their morphometry.

## EVIDENCE OF EUTROPHICATION

The present trophic nature of the Great Lakes is to a considerable degree the result of their gradual aging since formation. Evidence is accumulating, however, which indicates that human activity is greatly accelerating the eutrophication of all of the lakes but Lake Superior. This evidence is most spectacular for Lake Erie. A difficult problem is one of finding acceptable indices of change.

Various criteria have been used by different investigators to demonstrate eutrophication. Hasler (1947) compiled information on 37 lakes affected by enrichment from domestic and agricultural drainage. Among the changes in many of these lakes were: the dramatic decline and disappearance of salmonid fishes and increases in populations of coarse fish; changes in the species composition of plankton; and blooms of blue-green algae. Special significance has been attached to blooms of *Oscillatoria rubescens*. As the Untersee of Lake Zürich changed from a salmonid to a coarse-fish lake, plankton abundance increased, different species became dominant in the plankton, transparency decreased, and the dissolved oxygen content of the deep waters decreased. At the same time, the concentrations of chlorides and organic matter increased (Minder 1918, 1938, 1943). Minder (1938) attributed the increase and changes in the plankton to the growing amount of phosphorus and nitrogen from domestic sources. *Oscillatoria rubescens* appeared explosively in 1898 and replaced the formerly dominant *Fragilaria capucina*. The cladoceran *Bosmina longirostris* replaced *B. coregoni* after 1911. Blooms of *Oscillatoria rubescens*, declines in the hypolimnetic oxygen, decrease in transparency, and increases in the abundance of plankton were cited by Edmondson, Anderson, and Peterson (1956) as evidence of eutrophication of Lake Washington. They held this increased productivity to be the result of growing discharges of treated sewage into the lake. Similar changes were observed in Fure Lake by Berg et al. (1958). Species composition of the phytoplankton changed, transparency decreased, dissolved oxygen concentrations became low in the hypolimnion, and conductivity rose. These changes have occurred during the last 40 to 50 years. Berg (Berg et al. 1958, p. 176) stated, "The cause is an increased introduction of material with the sewage."

Our knowledge of the limnology of the Great Lakes in earlier years is seriously deficient. Observations useful for tracing changes in the Great Lakes are mostly limited to water-quality data, commercial fishing records, and a few observations on plankton. The fishing records and chemical data have the longest history and are the most reliable.

### *Chemical characteristics*

Chemical data representative of the lakes proper were compiled from many sources (Table 3) ranging from isolated samplings and water-intake data to extensive lake-wide sampling. Consequently, records for a particular year may represent an average of hundreds, thousands, or only a few determinations. Data on magnesium were available from most of the sources plotted in Figures 2 and 3, but they are not included because no significant change in concentration could be detected in any of the lakes. For example, magnesium concentrations in Lake Erie averaged 7.6 ppm in 1907 (Dole 1909), 8.0 ppm in 1934 (Mangan, Van Tuyl, and White 1952), and 8.0 ppm in recent years (Bureau of Commercial Fisheries data). Broadly speaking, there has been no significant change in Lake Superior. Other lakes in order of increasing chemical change are Huron, Michigan, Erie, and Ontario.

*Lake Superior*—The indicated slight downward trend in total dissolved solids in Lake Superior is not significant and concentrations have remained at approximately 60 ppm throughout the years (Fig. 1). Calcium, chloride, and sulfate concentrations also have remained the same since 1886 (Fig. 2). The close agreement among analyses of Lake Superior water by various individuals using different methods and techniques is unusual. The slight decrease in the sodium-plus-potassium content of the

TABLE 3. *Sources of data used in preparing Figs. 1, 2, and 3*

| Source and date | Data |
|---|---|
| Allen (1964) | Major ions, south-central Lake Huron, 1956. |
| Bading (1909) | Chlorides, Lake Michigan, 1909. |
| Barnard and Brewster (1909) | Chlorides, Lake Michigan, 16 Sept 1908, table 29. |
| Bartow and Birdsall (1911) | Major ions, average concentrations in 10 open Lake Michigan samples collected about 1910. |
| Beeton, Johnson, and Smith (1959) | Major ions, Lake Superior, 1953. |
| Birge and Juday (no date) | Total dissolved solids, Lake Erie, 1928-1930; data on analyses for total dissolved solids by L. A. Youtz for Lakes Erie, Huron, and Superior, 1928. |
| Bowles (1909) | Total dissolved solids, Lake Michigan, April 1908. |
| Collins (1910) | Major ions, Lake Michigan, 1885, from J. H. Long; total dissolved solids and chlorides, Chicago, average of weekly values 1897–1900. |
| Clarke (1924) | Major ions, Lake Michigan, Milwaukee, 1877; Kenosha and Racine, Wis., 1911. |
| Dole (1909) | Major ions and total dissolved solids, Lakes Erie, Huron, Michigan, Ontario, and Superior, averages of monthly determinations 1906–07. |
| Eddy (1943) | Major ions and total dissolved solids, Lake Superior, 1934. |
| Erie, Pa., Bur. Water (1956, 1957, 1959) | Major ions and total dissolved solids, Lake Erie, 1956, 1957, 1959. |
| Fish (1960) | Chlorides, Lake Erie, 1929. |
| Hunt (1857) | Major ions in water collected at Pointe des Cascades, Vandreuil, Que., Lake Ontario, 1854. |
| International Joint Commission (1951) | Chlorides and total dissolved solids, open Lake Erie near Detroit River mouth, sampling ranges P-1-W and LC, table N-17; open Lake Huron above Port Huron; open Lake Ontario, sampling locations 4 miles (6.4 km) or more from Niagara River, 1946–48. |
| Jackson (1912) | Chlorides and total dissolved solids, Lake Erie, 1910, tables 69, 70; 1911, tables 71, 72; 1912, table 68. |
| Kramer (1961) | Major ions, except potassium, Lake Erie, 1961. |
| Kramer (1962) | Major cations, western Lake Ontario, 1959. |
| Lake Michigan Water Commission (1909) | Chlorides and total dissolved solids, Lake Michigan, October 1908. |
| Lane (1899) | Sodium chloride, Lake Huron, 12 miles (19.3 km) above Port Huron and Alpena, Mich., 1895; Lake Michigan, 5 miles (8 km) off Milwaukee, Wis., 1895–99; total solids, Chicago, Ill., 1895; major ions and total dissolved solids, open Lake Superior 50 miles (80 km) from Keweenaw Pt., 1886. |
| Lenhardt (1955) | Major ions and total dissolved solids, Lake Michigan, 1954. |
| Leverin (1942) | Major ions and total dissolved solids, Lake Huron, Pt. Edward, Ont., 1934–37; Lake Ontario, average of 6 analyses, Kingston, Ont., 1934–38 and 1940. |
| Leverin (1947) | Major ions and total dissolved solids, Lake Erie, average of 6 determinations, Fort Erie, Ont., 1934–38; Lake Ontario, average of 7 determinations, Toronto, Ont., 1934–38; Lake Superior, average of 5 determinations, Sault Ste. Marie, Ont., 1936–38, one sample taken in open lake midway between Fort William and Sault Ste. Marie, 1942. |
| Lewis (1906) | Chlorides and total dissolved solids, Lake Erie, average of 6 analyses, Erie, Pa., 1901–1903. |
| Mangan, Van Tuyl, and White (1952) | Major ions and total dissolved solids, Lake Erie, 1934, 1945, and 1951. |
| Michigan Water Resources Commission (1954) | Major ions and total dissolved solids, Lake Huron at Alpena, East Tawas, and Harbor Beach, Mich.; Lake Michigan at Muskegon, St. Joseph, and Traverse City, Mich.; Lake Superior at Calumet, Mich. |

TABLE 3. *(Continued)*

| Source and date | Data |
|---|---|
| Ohio, State of (1953) | Major ions, Lake Erie, Lorain, O., average values, 1950–52. |
| Reade (1903) | Major ions, Lake Ontario, water sample collected in the St. Lawrence River opposite Montreal, Que., 1884. |
| Thomas (1954) | Major ions and total dissolved solids, Lake Erie, at Chippawa, Ont.; Lake Huron at Goderich and Sarnia, Ont.; Lake Ontario at Gananoque and Port Hope, Ont.; Lake Superior at Sault Ste. Marie, Ont., averages of monthly analyses, 1948–49. |
| U.S. Geological Survey (1960) | Major ions and total dissolved solids, Lake Erie, Niagara River at Buffalo, N.Y.; Lake Ontario, St. Lawrence River at Cape Vincent, N.Y., analyses for August 1957. |
| U.S. Public Health Service (1961) | Chlorides, sulfates, and total dissolved solids, Lake Erie at Buffalo, N.Y.; Lake Huron at Port Huron, Mich.; Lake Michigan at Milwaukee, Wis.; Lake Ontario at Massena, N.Y.; Lake Superior at Duluth, Minn.; average values for Oct 1960–30 Sept 1961. |
| Wright (1955) | Chlorides, western Lake Erie, 1930. |

water probably is not real, because present analytical methods differ substantially from former ones. The uniformity in the chemical analyses here lends confidence to the reliability of the chemical data for the other lakes.

*Lake Huron*—The slight increase in total dissolved solids in this lake is probably real, since about 30% of the inflow to Lake Huron is from Lake Michigan, where dissolved solids have risen significantly (Fig. 1). The sodium-plus-potassium content has remained about the same over the years of record. Some rather low values were reported for these ions during the 1930's, but the 1890–1910 data agree with recent determinations (Fig. 2). An increase of 3 ppm in chloride appears to have occurred during the past 30 years. The major source of chlorides within the Lake Huron watershed is in the Saginaw Valley, where considerable quantities of brine are pumped to the surface in the oil fields and for use in the chemical industry. The increased influx of brine during the past 30 years may account for most of the increase in chloride in the lake. Sulfate concentrations have increased 7.5 ppm in the past 54 years.

*Lake Michigan*—Total dissolved solids have increased about 20 ppm since 1895 (Fig. 1). Calcium has remained constant (Fig. 2). The greatest increase in any ion in Lake Michigan has been that of sulfate, which has risen 12 ppm since 1877. The chloride concentrations have risen slowly but steadily by 4 ppm. The sodium-plus-potassium content has not changed since 1907 but it exceeds that extant in 1877–1900. The determinations before 1907 may be too low, since they are below those reported for Lakes Huron and Superior. If, however,

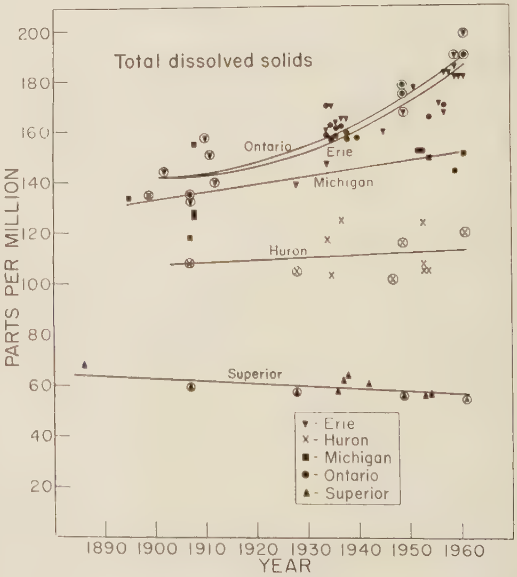

FIG. 1. Concentrations of total dissolved solids in the Great Lakes. Circled points are averages of 12 or more determinations. Data are from sources presented in the bibliography and Table 3.

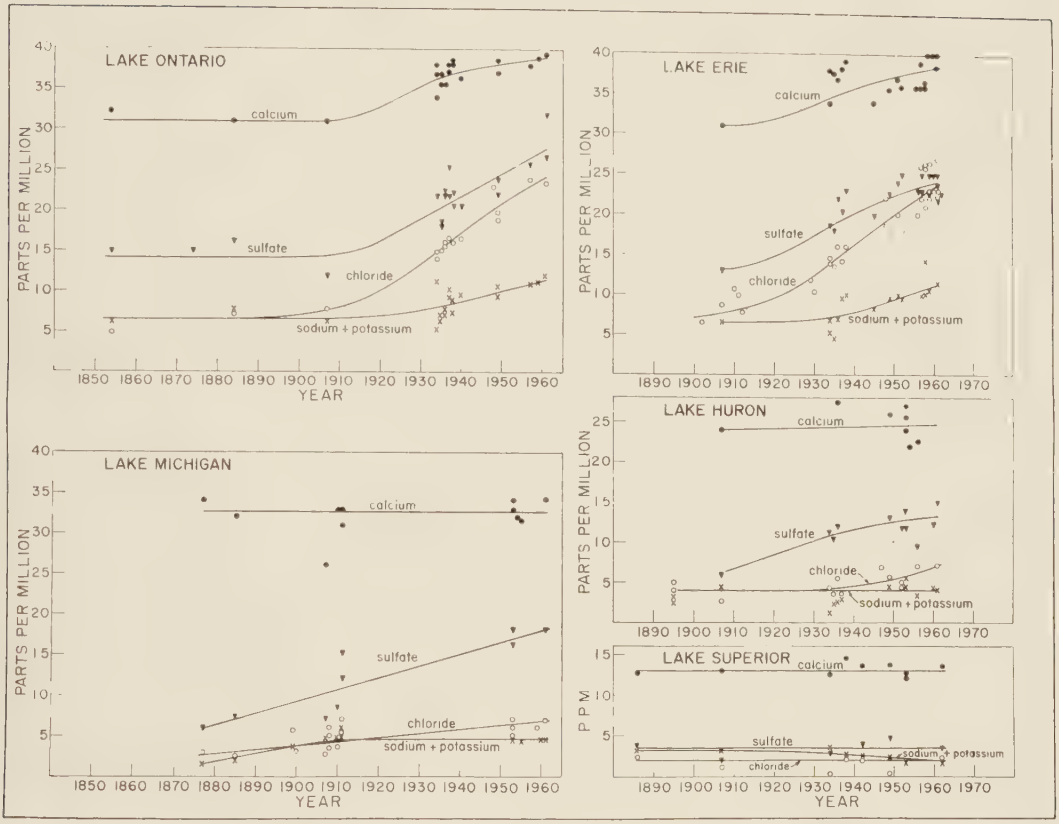

FIG. 2. Changes in the chemical characteristics of Great Lakes waters. Data for Lake Erie, 1958; Lake Huron, 1956; Lake Michigan, 1954, 1955, 1961; Lake Ontario, 1961; Lake Superior, 1952, 1953, 1961, 1962 are from the Ann Arbor Biological Laboratory, U.S. Bureau of Commercial Fisheries. Other data are from sources presented in the bibliography and Table 3.

these early determinations are reasonably accurate, the increase that occurred between 1877 and 1907 may be attributed to population growth in the Chicago area. The population of Chicago exceeded 1 million in 1890 and the Chicago Sanitary Canal, to divert sewage from the lake, was not completed until 1900. Consequently, during these early years considerable amounts of raw sewage entered the lake at Chicago.

*Lake Erie*—Total dissolved solids, calcium, chloride, sodium-plus-potassium, and sulfate all increased significantly in Lake Erie during the past 50 years. Total dissolved solids have risen by almost 50 ppm (Fig. 1). Increases of approximately 8, 16, 5, and 11 ppm have taken place in the concentrations of calcium, chloride, sodium-plus-potassium, and sulfate, respectively (Fig. 2).

*Lake Ontario*—The rate of increase in total dissolved solids in Lake Ontario has been the same as in Lake Erie. This rate was similar to that occurring in Lake Michigan prior to the late 1920's but has been higher than in Lake Michigan since about 1930 (Fig. 1). Close agreement of chemical data for Lake Ontario for 1854 and 1884 with those for 1907 indicates that the chemical characteristics of the water were altered little during this period (Fig. 2). Calcium, chloride, and sodium-plus-potassium increased to the same extent as noted in Lake Erie since 1910. Sulfate concentrations increased by 13 ppm, which is somewhat higher than in Lake Erie.

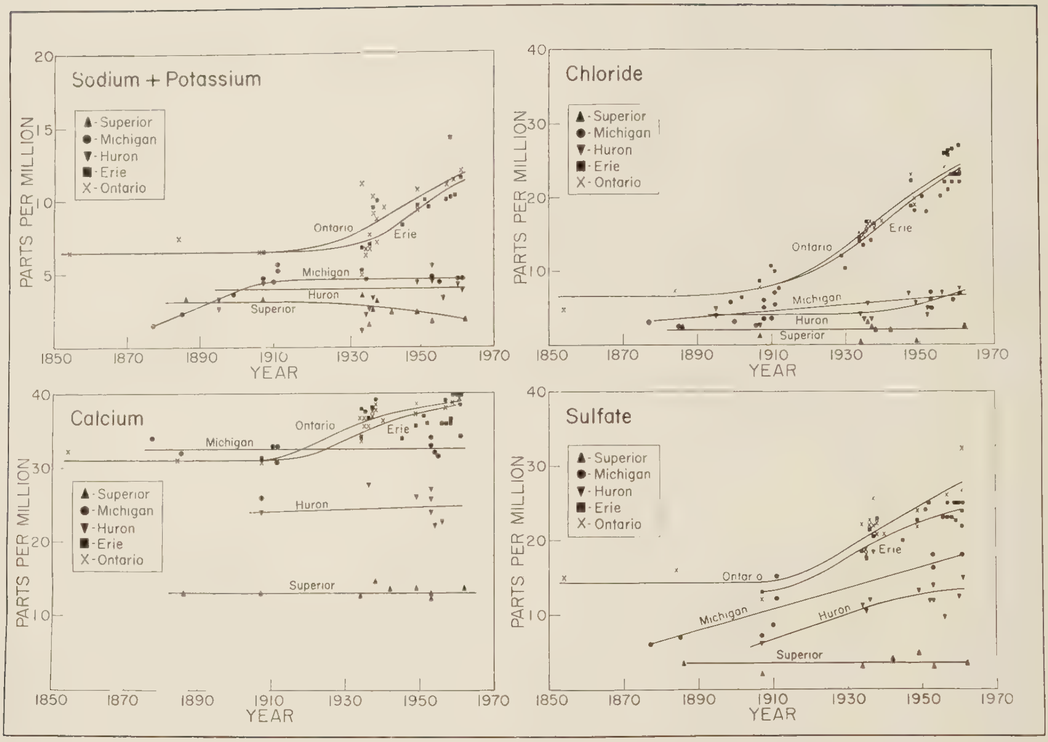

Fig. 3. Changes in the concentrations of calcium, chloride, sodium-plus-potassium, and sulfate in each of the Great Lakes. Sources of data same as for Fig. 2.

*Summary of chemical changes*—The extent of change in total dissolved solids in Lakes Erie, Michigan, and Ontario has not been as great as that indicated by Ayers (1962) for Lake Michigan or by Rawson (1951) for Lakes Erie and Ontario; both used the observations of Dole (1909) in 1906–1907 as their base. Dole's estimates of total dissolved solids (and of various ions as well) for these lakes were 9 to 16 ppm lower than those of several other investigators during this period. The 1907 data for Lake Michigan on sulfate, chloride, and especially calcium probably were all low because Dole collected his samples in the Straits of Mackinac where Lake Michigan water enters Lake Huron and the mixing of the water from these two lakes, as well as the occasional inflow of Lake Superior water into this area, could produce low concentrations of ions.

Changes in the chemical characteristics of Lake Ontario have closely paralleled those in Lake Erie (Fig. 3). Prior to 1910 the chemical characteristics of the two lakes were similar and conditions in Lake Erie were probably the same as indicated by the 1854 and 1884 analyses of Lake Ontario water. Concentrations of calcium, chloride, sodium-plus-potassium, and sulfate have been somewhat higher in Lake Ontario than in Lake Erie during the past 50 years. The greater concentrations of salts in Lake Ontario probably can be attributed to growth of the Toronto, Hamilton, and Rochester metropolitan areas and the industrial expansion along the upper Niagara River.

Lakes Erie and Ontario are the only lakes in which calcium increased materially (Fig. 3). Increases in sulfate have been significant in all of the lakes except Superior. The 11 ppm and 13 ppm increases in Lakes Erie and Ontario have taken place in 30 years, whereas the rise of 12 ppm in Lake Michigan has been more gradual over a period of 84 years. The sulfate change in Lake Huron parallels that in Lake Michigan and may have resulted largely from the inflow of Lake Michigan waters. The degree of change in the chloride content of Lakes Erie and Ontario is similar to that for sulfate, but chloride has not increased as much as sulfate in Lakes Huron and Michigan.

### *Plankton*

Few plankton data are available for Lakes Huron, Ontario, and Superior, especially for earlier years. Some rather extensive plankton data do exist, however, for Lakes Erie and Michigan.

*Lake Michigan*—Studies of Lake Michigan phytoplankton by Briggs (1872), Thomas and Chase (1886), Eddy (1927), Ahlstrom (1936), Damann (1945), and Williams (1962) show that the diatom species dominant 90 years ago have maintained their importance. The relative abundance and occurrence of individual species give no evidence of change in the phytoplankton. (Some confusion exists over the identification of certain species and some species are listed by one investigator and not by another.)

The best information of change of plankton abundance probably comes from Damann's (1960) publication on 33 years of plankton data from the Chicago water intake which showed an average increase of 13 organisms per ml per year in the standing crop of the total plankton. Damann's work, and indeed most of the past work on plankton, has been in the extreme southern end of the lake except for the open-lake data of Ahlstrom (1936). Damann (1945, p. 771) pointed out that the data he published ". . . are an expression of the plankton activity in only a small portion of the southwestern corner of Lake Michigan."

Recent plankton collections during July 1960 to July 1961 from Gary, Indiana, at the southern end of the lake, and Milwaukee, Wisconsin, near the middle of the lake (Williams 1962), show considerable differences between these two localities. The average phytoplankton count at Milwaukee was 975 plankters/ml. This figure is close to the annual average of 952/ml for the Chicago water intake 1926–1942 (Damann 1960). The average phytoplankton count at Gary was 1,914 plankters/ml, well above the annual average of 1,222/ml reported at Chicago for 1943–1958 (Damann 1960). Local differences in the relative importance of the major diatom species at Gary and Milwaukee also are apparent. Sampling by the Bureau of Commercial Fisheries, in 1960, yielded further evidence of wide variability. The relative abundance of the plankton species was different from that at the Gary and Milwaukee water intakes, and a much higher abundance of plankton was obtained with nets towed vertically. Plankton counts in the open-lake samples ranged from about 450 to 12,000 plankters/ml and averaged around 4,500/ml.

Two changes in the species composition of the zooplankton of Lake Michigan may be of some consequence. Apparently the cladoceran, *Bosmina longirostris,* has replaced *B. coregoni.* A similar change was noted as evidence of eutrophication in Lake Zürich (Minder 1938). Wells (1960) did not find *B. coregoni,* although *B. longirostris* was present in all of his 1954 and 1955 samples. *Bosmina coregoni* (*B. longispina*) was the most abundant cladoceran in samples collected in 1887–1888 and 1926–1927, and *B. longirostris* was listed as rare (Eddy 1927). *Bosmina coregoni* is an important component of the Lake Superior plankton (Putnam and Olson 1961), whereas *B. longirostris* has been important in Lake Erie plankton for many years (Fish 1960; Davis 1962).

The other possible change in the Lake Michigan plankton is the increased prominence of *Diaptomus oregonensis.* This species was not found by Eddy (1927), but Wells (1960) reported it to be present on all collection dates and it was a dominant diaptomid in the fall of 1955.

*Lake Erie*—Some significant changes have been observed in the plankton of Lake Erie. Evidently copepods and especially cladocerans have shown a marked increase in abundance since 1939 (Bradshaw 1964). Bradshaw attached some importance to the "recent" occurrence of the cladocerans *Eurycerus lamellatus, Chydorus sphaericus,* and *Ilyocryptus* sp., since they had not been found by Chandler (1940) in 1938–1939. *Eurycerus lamellatus, Chydorus sphaericus,* and two species of *Ilyocryptus* were present, however, in 1929 (Fish 1960). A copepod, *Diaptomus siciloides,* which was reported as "incidental" in Lake Erie plankton in 1929 and 1930 (Wright 1955), is now one of the two most abundant diaptomids (Davis 1962). Marsh's (unpublished manuscript) account of plankton in 1929 and 1930 included the statement, "The occurrence of *Diaptomus siciloides* in Lake Erie is a matter of decided interest, as it has never before been found in any of the Great Lakes." Later he continued, "*D. siciloides* may be considered an accidental intruder in the lake plankton . . ."

## CHANGES IN LAKE ERIE

Several important changes in Lake Erie have not been detected in the other lakes; all indicate an accelerated rate of eutrophication.

### *Fish populations*

The abundance of several commercially important fishes in Lake Erie has changed markedly during the past 40 years.[2] The fish populations of all of the lakes have changed but most changes, except in Lake Erie, have been the direct or indirect consequence of the buildup in sea lamprey populations (Smith 1964). The sea lamprey has not been important in Lake Erie, where few of the tributaries offer suitable spawning conditions.

The lake herring or cisco contributed around 20 million pounds (9 million kg) annually and as much as 48.8 million pounds (22.1 million kg) to the commercial catch (U.S. and Canada) prior to 1925. In 1925, the production declined to 5.8 million pounds (2.6 million kg) and continued to decrease. The take has amounted to a fraction of that since the early 1930's, except for landings of more than 2 million pounds (about 1 million kg) in 1936 and 1937 and a production of 16.2 million pounds (7.4 million kg) in 1946. The total production was only 7,000 pounds (3,200 kg) in 1962.

The whitefish fishery has been at an all-time low since 1948. The 1962 catch was 13,000 pounds (6,000 kg), whereas production had been 2 million pounds (1 million kg) or more for many years.

The sauger was contributing 1 million pounds (500,000 kg) or more to the commercial production prior to 1946. The catch has not reached 0.5 million pounds (0.22 million kg) since 1945 and has declined progressively since 1953. Production has been only 1 to 4 thousand pounds (450–1,800 kg) in recent years.

The walleye production increased during the 1940's and 1950's to reach 15.4 million pounds (7 million kg) in 1956. Production has decreased since 1958 and recently it has amounted to less than 1 million pounds (450,000 kg).

The commercial catch of blue pike has dropped disastrously. The production fluctuated around an average of about 15 million pounds (6.8 million kg) for many years. The landings dropped to 1.4 million pounds (640,000 kg) in 1958, to 79,000 pounds (36,000 kg) in 1959, and to only 1,000 pounds (450 kg) in 1962. Of the few blue pike caught in 1963, most were more than 10 years old.

The total production of all species in Lake Erie continues to be around 50 million pounds (22.7 million kg), but only because more freshwater drum (sheepshead), carp, yellow perch, and smelt are being caught than in the past. The major factor in the decline in the commercial catch of the more desirable species has been their failure to reproduce.

### *Bottom fauna*

The changes in the species composition of the bottom fauna of the area west of the islands in Lake Erie have been sweeping. Carr and Hiltunen (unpublished manuscript)[3] have shown that few of the formerly

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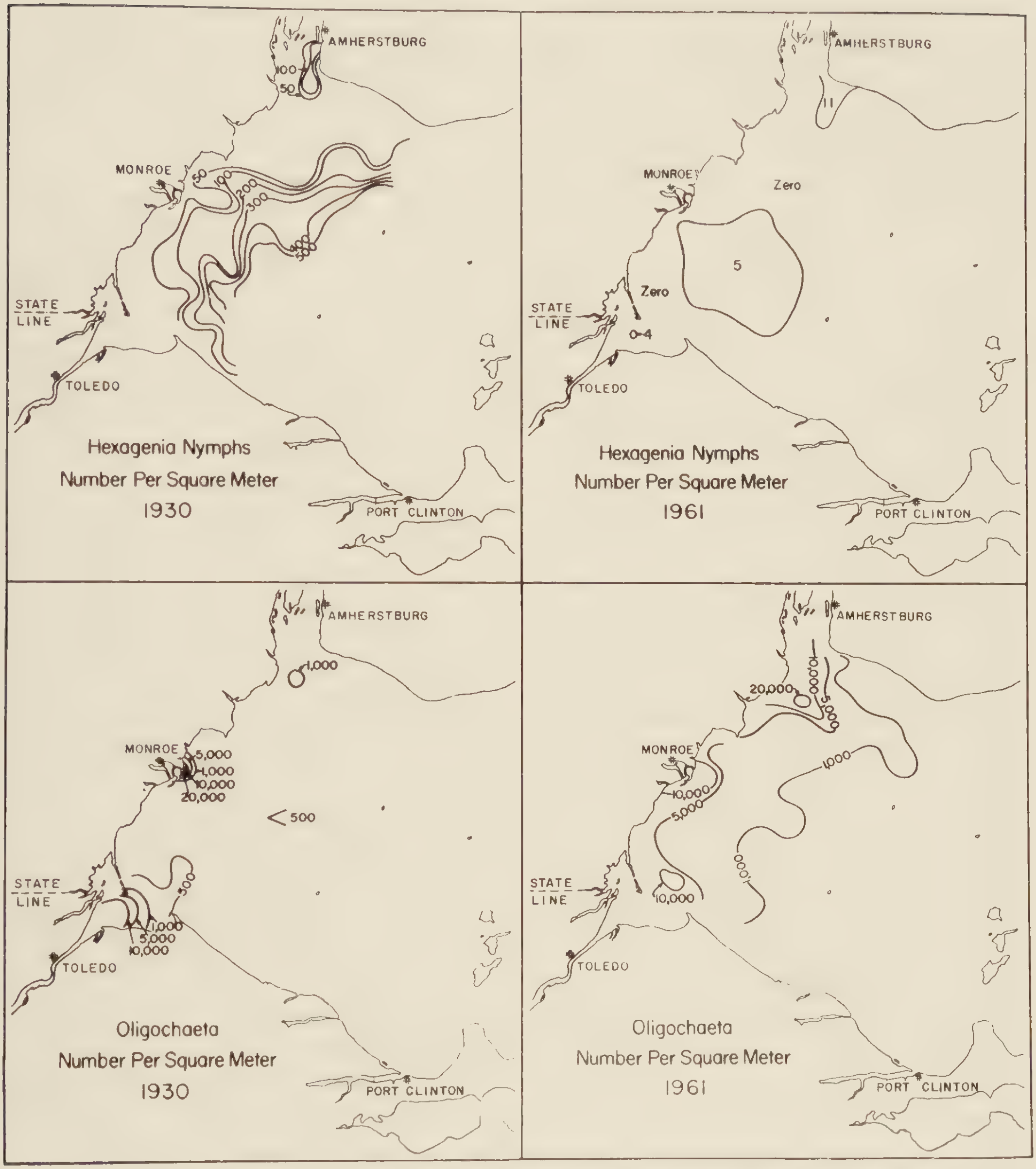
[2] Statistical data cited are from Baldwin and Saalfeld (1962).

[3] Carr, J. F., and J. K. Hiltunen. Changes in the bottom fauna of Lake Erie, west of the islands, 1930–1961. Paper presented at the 11th annual meeting Midwest Benthological Society, Murfreesboro, Tenn., 18 April 1963.


AMHERSTBURG
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PORT CLINTON

Hexagenia Nymphs
Number Per Square Meter
1930

Hexagenia Nymphs
Number Per Square Meter
1961

Oligochaeta
Number Per Square Meter
1930

Oligochaeta
Number Per Square Meter
1961

FIG. 4. Distribution and abundance of *Hexagenia* nymphs and oligochaetes in western Lake Erie, 1930 and 1961.

abundant mayfly nymphs (*Hexagenia*) now inhabit this area and that tubificids are far more abundant now than 30 years ago (Fig. 4). Midge larvae and tubificids have increased and mayflies have decreased also among the islands and in the western part of the central basin (Beeton 1961).

### *Dissolved oxygen*

Synoptic surveys of Lake Erie in 1959 and 1960 have demonstrated that low dissolved oxygen concentrations (3 ppm or less) appear in about 70% of the hypolimnetic waters of the central basin during late summer (Beeton 1963). Scattered observations of some relatively low dissolved oxygen concentrations have been made during the past 33 years. The information we have indicates that the severity of depletion is more frequent and greater now than in the past and probably affects a more extensive area (Carr 1962).

## CONCLUSION

The chemical content of the water in all of the Great Lakes except Lake Superior has changed in some measure. The biota also has changed in Lake Michigan and especially Lake Erie. These changes, remarkable for such large lakes, are those characteristic of eutrophication in smaller lakes and have come about over the relatively short time of 50 to 60 years. Man's activities clearly have accelerated the rate of eutrophication. This rate has been greatest in Lakes Erie, Ontario, and Michigan and these lakes have had the largest population growth within their drainage areas. An indication of the growth of population comes from census data for the northeast central states; the population there increased from 4.5 million to 16 million between 1850 and 1900, and by 1960 the population was 36.3 million. The rate of population growth increased sharply after 1910. The substantial increases in the chemical content of the waters of Lakes Erie and Ontario also have appeared since 1910. The increases have been greatest for chloride and sulfate, both of which are conspicuous in domestic and industrial wastes, whereas magnesium concentrations have not changed measurably. Most of the magnesium comes from the limestones in the Lake Michigan basin; the stability of magnesium concentrations, therefore, indicates no appreciable change in the erosion of these deposits. The population along Lake Superior always has been sparse. The population along Lake Huron has been far less than on Lakes Michigan, Erie, and Ontario. Most changes in the open-lake waters of Lake Huron have resulted from the inflow of Lake Michigan water. Undoubtedly, Saginaw Bay, Lake Huron, has been changed appreciably by the extensive growth of industry and agriculture within the Saginaw River valley during the past 50 years. High chloride concentrations have been measured in the bay (Adams 1937); no attempt has been made, however, to assess the extent of change.

## REFERENCES

Adams, M. P. 1937. Saginaw Valley report. Mich. Stream Control Commission. 156 p.

Ahlstrom, E. H. 1936. The deep-water plankton of Lake Michigan, exclusive of the Crustacea. Trans. Am. Microscop. Soc., **55**: 286–299.

Allen, H. E. 1964. Chemical characteristic of south-central Lake Huron. Great Lakes Res. Div., Inst. Sci. and Tech., Univ. Mich., Publ. No. 11, p. 45–53.

Ayers, J. C. 1962. Great Lakes waters, their circulation and physical and chemical characteristics. Am. Assoc. Advan. Sci., Publ. No. 71, p. 71–89.

Bading, G. A. 1909. Water conditions at Milwaukee. Lake Michigan Water Comm., Rept. No. 1, p. 36–39.

Baldwin, N. S., and R. W. Saalfeld. 1962. Commercial fish production in the Great Lakes 1867–1960. Great Lakes Fish. Comm., Tech. Rept. No. 3. 166 p.

Barnard, H. E., and J. H. Brewster. 1909. The sanitary condition of the southern end of Lake Michigan, bordering Lake County, Indiana. Lake Michigan Water Comm., Rept. No. 1, p. 193–266.

Bartow, E., and L. I. Birdsall. 1911. Composition and treatment of Lake Michigan water. Lake Michigan Water Comm., Rept. No. 2, p. 69–86.

Beeton, A. M. 1961. Environmental changes in Lake Erie. Trans. Am. Fisheries Soc., **90**: 153–159.

———. 1963. Limnological survey of Lake Erie 1959 and 1960. Great Lakes Fish. Comm., Tech. Rept. No. 6. 32 p.

———, J. H. Johnson, and S. H. Smith. 1959. Lake Superior limnological data. U.S. Fish Wildlife Serv., Spec. Sci. Rept. Fisheries No. 297. 177 p.

Berg, K., K. Andersen, T. Christensen, F. Ebert, E. Fjerdingstad, C. Holmquist, K. Korsgaard, G. Lange, J. M. Lyshede, H. Mathiesen, G. Nygaard, S. Olsen, C. V. Otterstrøm, U. Røen, A. Skadhauge, E. Steemann Nielsen. 1958. Investigations on Fure Lake 1950–54. Limnological studies on cultural influences. Folia Limnol. Scandinavica, 10(1958). 189 p.

Birge, E. A., and C. Juday. No date. The organic content of the water of Lake Erie. Supplemental data to "A limnological survey of western Lake Erie with special reference to pollution," by Stillman Wright. Ohio Div. Wildlife. Unpublished manuscript. 281 p.

BOWLES, J. T-B. 1909. Investigation of typhoid fever epidemic at Sheboygan, Wisconsin. Lake Michigan Water Comm., Rept. No. 1, p. 90–95.

BRADSHAW, A. S. 1964. The crustacean zooplankton picture: Lake Erie 1939–49–59; Cayuga 1910–51–61. Verhandl. Intern. Ver. Limnol., **15**: 700–708.

BRIGGS, S. A. 1872. The Diatomaceae of Lake Michigan. The Lens, **1**: 41–44.

BRUNDIN, L. 1958. The bottom faunistical lake type system. Verhandl. Intern. Ver. Limnol., **13**: 288–297.

CARR, J. F. 1962. Dissolved oxygen in Lake Erie, past and present. Great Lakes Res. Div., Inst. Sci. and Tech., Univ. Mich., Publ. No. 9, p. 1–14.

CHANDLER, D. C. 1940. Limnological studies of western Lake Erie. I. Plankton and certain physical-chemical data of the Bass Islands Region, from September, 1938, to November, 1939. Ohio J. Sci., **40**: 291–336.

COLLINS, W. D. 1910. The quality of the surface waters of Illinois. U.S. Geol. Surv., Water Supply Papers, 239. 94 p.

CLARKE, F. W. 1924. The composition of the river and lake waters of the United States. U.S. Geol. Surv., Profess. Papers, No. 135. 199 p.

DAMANN, K. E. 1945. Plankton studies of Lake Michigan. I. Seventeen years of plankton data collected at Chicago, Illinois. Am. Midland Naturalist, **34**: 769–796.

———. 1960. Plankton studies of Lake Michigan. II. Thirty-three years of continuous plankton and coliform bacteria data collected from Lake Michigan at Chicago, Illinois. Trans. Am. Microscop. Soc., **79**: 397–404.

DAVIS, C. C. 1962. The plankton of the Cleveland Harbor area of Lake Erie in 1956–1957. Ecol. Monographs, **32**: 209–247.

DOLE, R. B. 1909. The quality of surface waters in the United States. Part I. Analyses of waters east of the one hundredth meridian. U.S. Geol. Surv., Water Supply Papers, 236. 123 p.

DUNN, D. R. 1954. Notes on the bottom fauna of twelve Danish lakes. Vidensk. Medd. Dansk Naturhist. Foren., **116**: 251–268.

EDDY, S. 1927. The plankton of Lake Michigan. Illinois Nat. Hist. Surv. Bull., **17**: 203–232.

———. 1943. Limnological notes on Lake Superior. Proc. Minn. Acad. Sci., **11**: 34–39.

EDMONDSON, W. T., G. C. ANDERSON, AND D. R. PETERSON. 1956. Artificial eutrophication of Lake Washington. Limnol. Oceanog., **1**: 47–53.

ELSTER, H.-J. 1958. Das limnologische Seetypensystem, Rückblick und Ausblick. Verhandl. Intern. Ver. Limnol., **13**: 101–120.

ERIE, PENNSYLVANIA, BUREAU OF WATER. 1956. Ninetieth annual report, 1956. 63 p.

———. 1957. Ninety-first annual report, 1957. 63 p.

———. 1959. Ninety-third annual report, 1959. 56 p.

FISH, C. J. 1960. Limnological survey of eastern and central Lake Erie, 1928–1929. U.S. Fish Wildlife Serv. Spec. Sci. Rept. Fisheries, No. 334. 198 p.

HASLER, A. D. 1947. Eutrophication of lakes by domestic drainage. Ecology, **28**: 383–395.

HUNT, T. S. 1857. The chemical composition of the waters of the St. Lawrence and Ottawa Rivers. Phil. Mag., Ser. 4, **13**: 239–245.

INTERNATIONAL JOINT COMMISSION. 1951. Report of the International Joint Commission United States and Canada on pollution of boundary waters. Washington and Ottawa. 312 p.

JACKSON, D. D. 1912. Report on the sanitary conditions of the Cleveland water supply. Cleveland. 148 p.

KRAMER, J. R. 1961. Chemistry of Lake Erie. Great Lakes Res. Div., Inst. Sci. and Tech., Univ. Mich., Publ. No. 7, p. 27–56.

———. 1962. Chemistry of western Lake Ontario. Great Lakes Res. Div., Inst. Sci. and Tech., Univ. Mich., Publ. No. 9, p. 21–28.

LAKE MICHIGAN WATER COMMISSION. 1909. Comparative analysis of samples of water from Lake Michigan. Rept. No. 1, p. 103–105.

LANE, A. C. 1899. Lower Michigan waters: a study into the connection between their chemical composition and mode of occurrence. U.S. Geol. Surv. Water-supply Irrigation Papers, 31. 97 p.

LENHARDT, L. G. 1955. Water quality and water usage of the Great Lakes public water supplies. The Great Lakes and Michigan. Great Lakes Res. Inst., Univ. Mich., p. 13–15.

LEVERIN, H. A. 1942. Industrial waters of Canada. Can. Dept. Mines Resources, Mines Geol. Branch, Rept. 807. 112 p.

———. 1947. Industrial waters of Canada. Can. Dept. Mines Resources, Mines Geol. Branch, Rept. 819. 109 p.

LEWIS, S. J. 1906. Quality of water in the upper Ohio River basin and at Erie, Pa. U.S. Geol. Surv. Water-supply Irrigation Papers, 161. 114 p.

MANGAN, J. W., D. W. VAN TUYL, AND W. F. WHITE, JR. 1952. Water resources of the Lake Erie shore region in Pennsylvania. U.S. Geol. Surv. Circ., 174. 36 p.

MARSH, C. D. No date. The Crustacea of the plankton of western Lake Erie. Supplemental data to "A limnological survey of western Lake Erie with special reference to pollution," by Stillman Wright. Ohio Div. Wildlife. Unpublished manuscript. 31 p.

MERNA, J. 1960. A benthological investigation of Lake Michigan. M.S. Thesis, Michigan State Univ. 74 p.

MICHIGAN WATER RESOURCES COMMISSION. 1954. Great Lakes water temperatures. Unpublished manuscript. 50 p.

MINDER, LEO. 1918. Zur Hydrophysik des Zürich u. Walensees, nebst Beitrag zur Hydrochemie u. Hydrobakteriologie des Zürichsees. Arch. Hydrobiol., **12**: 122–194.

———. 1938. Der Zürichsee als Eutrophierungsphänomen. Summerische Ergebnisse aus fünfzig Jahren Zürichseeforschung. Geol. Meere Binnengewässer, **2**: 284–299.

———. 1943. Neuere Untersuchungen über den Sauerstoffgehalt und die Eutrophie des Zürichsees. Arch. Hydrobiol., **40**: 279–301.

OHIO, STATE OF. 1953. Lake Erie pollution survey, supplement. Ohio Div. Water, Final Rept., Columbus, Ohio. 39 tables, 125 p.

PUTNAM, H. E., AND T. A. OLSON. 1961. Studies on the productivity and plankton of Lake Superior. School Public Health, Univ. Minn., Rept. No. 5. 58 p.

RAWSON, D. S. 1951. The total mineral content of lake waters. Ecology, **32**: 669–672.

———. 1955. Morphometry as a dominant factor in the productivity of large lakes. Verhandl. Intern. Ver. Limnol., **12**: 164–174.

———. 1956. Algal indicators of trophic lake types. Limnol. Oceanog., **1**: 18–25.

———. 1960. A limnological comparison of twelve large lakes in northern Saskatchewan. Limnol. Oceanog., **5**: 195–211.

READE, T. M. 1903. The evolution of earth structure. Longmans, Green, New York. 342 p.

RODGERS, G. K. 1962. Lake Ontario data report. Great Lakes Inst., Univ. Toronto, Prelim. Rept. No. 7. 102 p.

SMITH, S. H. 1964. Status of the deepwater cisco population of Lake Michigan. Trans. Am. Fisheries Soc., **93**: 209–230.

TEILING, E. 1955. Some mesotrophic phytoplankton indicators. Verhandl. Intern. Ver. Limnol., **12**: 212–215.

TETER, H. E. 1960. The bottom fauna of Lake Huron. Trans. Am. Fisheries Soc., **89**: 193–197.

THIENEMANN, A. 1928. Der Sauerstoff im eutrophen und oligotrophen See. Die Binnengewässer, Band 4, Schweizerbart, Stuttgart. 75 p.

THOMAS, F. J. F. 1954. Industrial water resources of Canada. Upper St. Lawrence River-central Great Lakes drainage basin in Canada. Can. Dept. Mines Tech. Surv., Water Surv. Rept. No. 3, Mines Branch Rept. 837. 212 p.

THOMAS, B. W., AND H. H. CHASE. 1887. Diatomaceae of Lake Michigan as collected during the last sixteen years from the water supply of the city of Chicago. Notarisia, Commetarium Phycologium, **2**: 328–330.

U.S. GEOLOGICAL SURVEY. 1960. Quality of the surface waters of the United States. U.S. Geol. Surv., Water Supply Papers, 1520. 641 p.

U.S. PUBLIC HEALTH SERVICE. 1961. National water quality network. Annual compilation of data October 1, 1960–September 30, 1961. U.S. Public Health Serv. Publ. 663. 545 p.

WELCH, P. S. 1952. Limnology. McGraw-Hill, New York. 538 p.

WELLS, LARUE. 1960. Seasonal abundance and vertical movements of planktonic Crustacea in Lake Michigan. U.S. Fish Wildlife Serv., Fishery Bull., **60**(172): 343–369.

WILLIAMS, L. G. 1962. Plankton population dynamics. U.S. Public Health Serv. Publ., 663. 90 p.

WRIGHT, STILLMAN. 1955. Limnological survey of western Lake Erie. U.S. Fish Wildlife Serv., Spec. Sci. Rept. Fisheries, 139. 341 p.

# BIOLOGY AND CHEMISTRY - ABSTRACTS

## SAMPLING EFFICIENCIES OF THREE KINDS OF DREDGES IN SOUTHERN LAKE MICHIGAN.

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Data are presented on the sampling efficiencies of the Petersen, orange-peel, and Smith-McIntyre dredges at various depths and in different sediments. Three bottom samples were taken with each dredge at depths of 3, 10, 20, 30, and 40 fathoms in four areas of southern Lake Michigan in 1962. The three dredges varied considerably in the number of organisms collected at any one depth, and samples from the Smith-McIntyre dredge usually contained more organisms per square meter of bottom than samples collected by the other dredges. Certain organisms collected by the Smith-McIntyre dredge were not present in samples taken by the other dredges from the same location. Previous studies of samples collected with Petersen dredges have led to establishment of zones of maximum population densities or changes in the benthic communities of Lake Michigan. These conclusions are questionable when compared with results obtained with samplers other than the Petersen dredge.

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# THE SPOTTED JACK CREVALLE, *CARANX MELAMPYGUS* CUVIER, IN THE EASTERN PACIFIC[1]

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**External morphological characters and their ontogeny in the juvenile-adult stages are described for the spotted jack crevalle, *Caranx melampygus*. *Caranx medusicola* is documented as a junior synonym.**

The spotted jack crevalle is one of the larger and more colorful jacks of the genus *Caranx*, family Carangidae. It occurs in tropical marine waters of the Pacific and Indian Oceans; in the eastern Pacific it is most abundant around tropical, offshore islands.

Many species of jack crevalles, and certainly this one, are significant components of the waters they inhabit; therefore a knowledge of their taxonomy and biology is necessary in comprehending and utilizing our marine resources. The developing, pelagic young are fed upon by tunas and other predatory fishes that are important to our fisheries' economy, and in turn young jacks compete for food with, and feed upon, the young of these other fishes. The adult jacks are strong, fast swimmers, are probably wide-ranging, and must be considered as significant competitors and predators of other fishes that are currently of more importance to commercial and sportfishing interests. However, the spotted jack crevalle is a valuable resource itself, and in Hawaii and other Pacific Islands, it is frequently eaten and considered very palatable. Its rating as a sport fish is excellent. The several that I have caught and seen caught trolling off the Tres Marias Islands, Mexico, showed them to be one of the better sportfishes there. The spotted jack strikes, runs, and fights hard.

Despite its importance, the spotted jack is not adequately known. By common name, this species has also been called blue jack, blue crevally, *'omilu,* and probably a variety of other names in restricted areas. The current common name seems more appropriate because this is the only jack crevalle that is spotted. Its scientific names have frequently been confused, and *Caranx medusicola* Jordan and Starks, long regarded as a distinct species endemic to the eastern Pacific, is documented here as a junior synonym of *Caranx melampygus*. Intraspecific variation and changes in ontogeny, that have not been adequately understood previously, are described here and will facilitate proper identification of this species. Methods of measurements and counts are as described by Berry (1959: 418-424), unless otherwise noted.

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## CHARACTERS

### Dorsal and Anal Spines

All specimens examined had eight spines in the first dorsal fin, one spine in the second dorsal, and an anal fin with three spines. Seven first dorsal spines have been reported by several authors, but these accounts probably represent abnormal specimens or relatively rare variants. In several of the largest specimens from the eastern Pacific, the first dorsal spine was fused along its posterior margin to the second and superficially the two appeared to be a single spine. The first two anal fin spines were separated from the third in the smallest specimen examined (63 mm SL). The first and second dorsal fins lose their membranous connection (joining the eighth and ninth spines) in fish between 80 and 84 mm SL. The eighth spine tends to lose its membranous connection with the seventh spine at larger sizes; they were separated in 556- and 572 mm specimens, but not quite separated in other large specimens examined (501 to 617 mm SL).

### Dorsal and Anal Soft-rays

In 85 specimens, dorsal soft-ray counts ranged from 21 to 23, and anal soft-rays from 18 to 20, with modes of D. 22 and A. 19. Counts for dorsal soft-rays as low as 20 (Williams, 1958) and as high as 25 (Weber and de Beaufort, 1931), and counts for anal soft-rays as low as 17 (Williams, 1958) have been reported.

### Gill Rakers

In 82 specimens, gill rakers on the first arch ranged from 7 to 9 on the upper limb plus 17 to 21 on the lower limb, with modes of 8 + 19. Four to six (usually five) gill rakers occur on the hypobranchial segment of the lower limb. Gill rakers at the anterior ends of the upper and lower limbs tend to become smaller or rudimentary with growth of the fish. For the upper limb, the smallest specimen with rudiments was 97.5 mm, and the largest without rudiments was 220 mm. For the lower limb, the smallest specimen with rudiments was 80 mm, and the largest without rudiments was 142 mm. The largest specimen (617 mm) had the maximum number of rudiments observed, six upper and three lower.

### Scutes

Scute formation along the straight portion of the lateral line is completed by about 80 mm SL. The lowest mean count (average of both sides) observed was 30 on a 74-mm specimen. An apparent decrease in the number on specimens larger than 400 mm is due to ontogenetic changes—spines on the scutes become blunt, and the posterior margins of the scutes become less angular, so that they are not distinguishable as such from the scales of the lateral line (following the definition of Berry, 1959: 422):

| | | |
|---|---|---|
| Size range (SL) | 80–306 mm | 415–617 mm |
| Mean scute counts, range | 32–41.5 | 31–36 |
| Mean scute counts, average | 36.68 | 33.0 |
| Number of specimens | 60 | 8 |
| Standard deviation | 2.0908 | 1.6475 |

This statistically significant decrease with growth is probably the reason differences in scute counts have been reported for *C. melampygus* and its synonym, *C. stellatus* (see reference to Weber and de Beaufort, 1931, under Synonymy). Considering the scute count from one side only of a fish (before the mean count for that fish is calculated), minimum and maximum counts I obtained were 30 and 42 scutes. A lower minimum count of 29 was reported for a specimen 398 mm FL by Lane (*MS*). All of the scales in the anterior part of the straight lateral line usually do not form into scutes (or in larger specimens some of them may lose their scute-like characteristics). Using counts from both sides of each fish, these anterior non-scutellate scales are:

| | | |
|---|---|---|
| Size range (SL) | 80–306 mm | 415–617 mm |
| Anterior straight lateral line scales, range | 0–8 | 1–9 |
| Anterior straight lateral line scales, average | 3.6 | 4.2 |

### Pigmentation

A series of preserved specimens showed an ontogenetic progression from a barred stage, through a clear phase with prominent, dark, dorsal- and anal-fin lobes, to a spot-covered body. The barred phase (Figure 1A) usually has clear soft-rayed fins and five vertical bars on the body (first and second bars under the spinous dorsal fin, third through fifth under the soft dorsal fin); an additional bar may be present on the nape and another on the anterior part of the peduncle, but these last two bars are usually indistinct or have faded on preserved specimens. The five body bars may extend nearly to the ventral body margin, but usually terminate just below the level of the straight lateral line; the ventral part of the fifth bar may be angled posteriorly. Bars were present on the smallest specimen examined (63 mm SL) and persisted on some specimens as large as 113 mm; but bars may be absent on some specimens as small as 83 mm. In a single large collection (UCLA W58-285) of *C. melampygus* 76 specimens (67.5-88.5 mm) all had body bars, and 37 larger specimens (90-154 mm) all lacked bars. Woods (in Schultz *et al.*, 1953: 513) recorded a 77-mm specimen as having

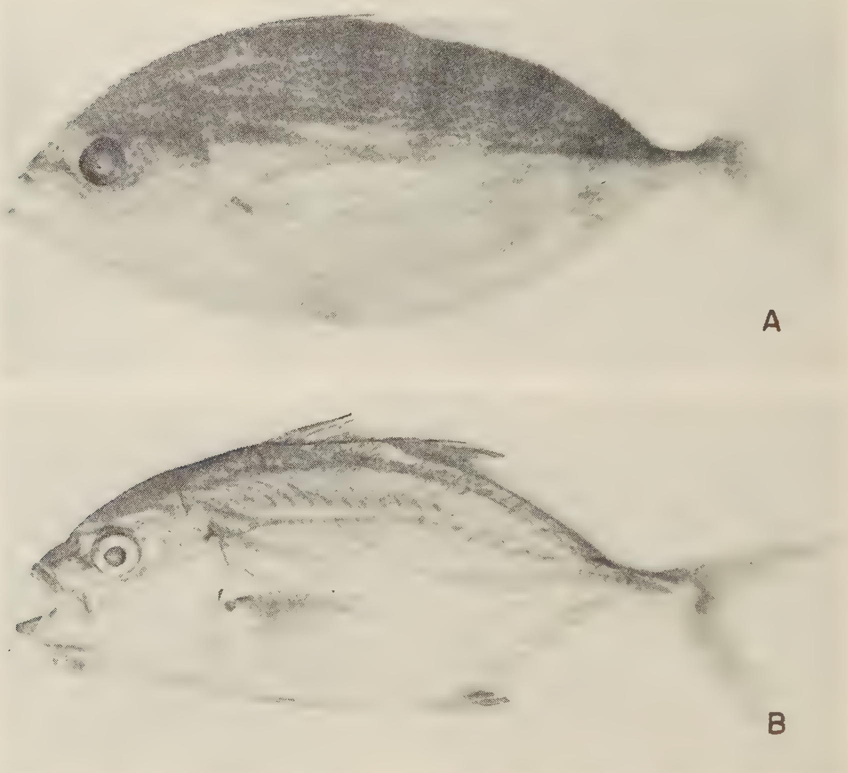

FIGURE 1. *Caranx melampygus,* unspotted stages. **A,** barred juvenile 74.5 mm SL, Clipperton Island, SIO 59-6. **B,** lectotype of *Caranx medusicola,* 123 mm SL, Mazatlán, Mexico, SU 2845. *Photography by Jim Ruppert, 1963.*

seven broad black bands. Spots begin to form on the head and body at approximately 150 to 200 mm SL, according to the following accounts:

| Spots absent | Spots present | Authority |
|---|---|---|
| 70 to less than 180 mm | 187–645 mm | Woods (in Schultz *et al.*, (1953) |
| 137–200 mm | 200–700 mm | Williams (1958) |
| 83–120 mm | 190–637 mm | Lane (MS) |
| 63–154 mm | 192-617 mm | Present study |

Only a few spots are present initially (Figure 2A), but the number rapidly increases with growth (Figure 2B). The first dorsal fin is dark at smaller sizes (*ca.* 70 mm) and becomes lighter at larger sizes. The soft-dorsal, anal, and caudal fins are relatively clear on the smallest specimens, become dusky, then dark at about 90 mm, especially on the lobes; dark pigmentation is most pronounced on the dorsal-fin lobe between about 90 and 150 mm. The pectoral fins become dusky at some size above 300 mm. The pelvic fins are dark or dusky, especially on their distal ends, above a size of 100 mm. There is no opercular spot. Eight specimens collected in the Tres Marias Islands during August

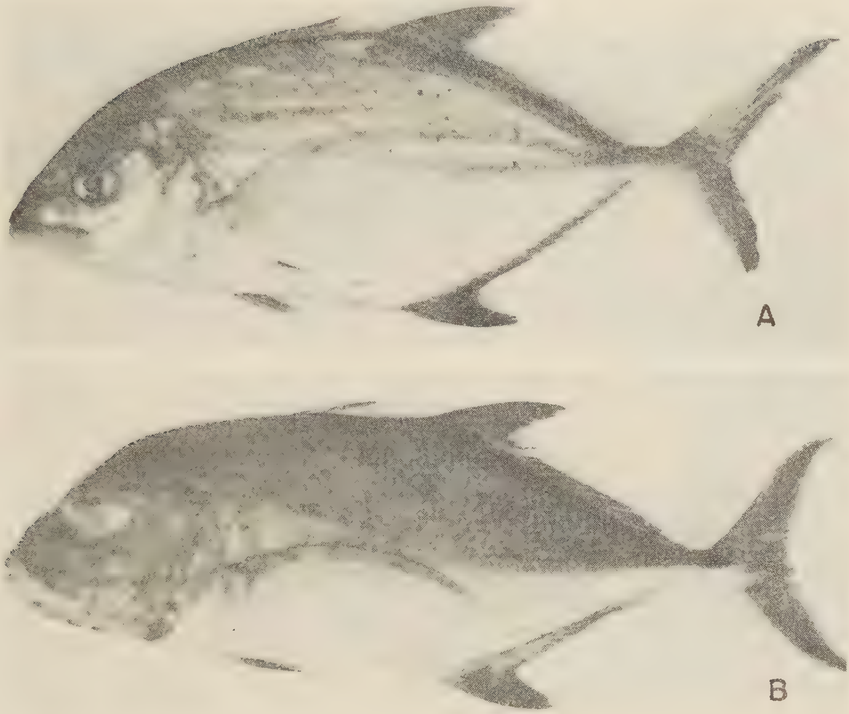

FIGURE 2. *Caranx melampygus*, spotted stage. **A**, 193 mm SL, Socorro Island, BC 59-261. **B**, adult male, 601 mm SL, Tres Marias Islands, BLLJ B6108-11. *Photography by Jim Ruppert, 1963.*

1961 give an indication that sexual dimorphism exists in pigmentation: five females, 501–597 mm, were generally light or clear below the level of the straight lateral line, and three males, 508–617 mm, were generally dark or dusky below with darker pelvic and caudal fins. Color notes from a fresh, 556-mm male caught at Cocos Island follow: the body generally dark above and light below, scutes of the straight lateral line with a darker cast than the rest of the body; a thin line of metallic blue along the base of the dorsal fin, below this to about half-way down to the lateral line a metallic olive-green flecked with metallic blue, dusky below this to level of lateral line; many black spots scattered over head (to about the level of upper part of maxillary) and body (concentrated dorsally to just below lateral line); dorsal spines relatively clear with faint olive cast; soft dorsal fin with bluish and blackish cast; anal spines white; anal soft-rays dark with bluish and blackish cast over most of the fin and with a narrow white margin posterior to anal lobe; caudal fin dark with a bluish cast over most of fin and with a light margin on leading edge of lower lobe; pectoral fins dusky on dorsal half, this area containing four yellow-olive streaks, and the fins becoming lighter to white below; pelvic fins dark or dusky on the rays with the interradial membranes whitish.

### Other Characters

The chest is completely scaled. Preopercular spines are unknown (absent on all specimens examined including the smallest, 63 mm SL). Posterio-lateral projections of interneural and interhaemal spines are produced and extend above the body surface along the dorsal and anal soft-rays in specimens to at least 151 mm SL, but reduced at larger sizes. Bilateral, paired caudal keels have developed by 68.5 mm SL. Dentition is typical of *Caranx (sensu stricto);* the upper jaw has an outer row of large, recurved canines and an inner band of smaller canines; the lower jaw has a single row of large canines; teeth in both jaws decrease in size posteriorly; teeth are present in a triangular patch on the vomer, in a narrow band on each palatine, and on the tongue. Branchiostegal rays number 7 (3+4). Pectoral fins have one spine and 19 to 21 (usually 20) soft-rays. Pelvic fins have one spine and five soft-rays. Vertebrae number 24 (10+14) in 134 specimens from eight collections.

## RANGE

The range of *C. melampygus* was recorded by Williams (1958: 383) as ''East coast of Africa from Red Sea to Natal; Madagascar. Throughout Tropical and Indo-Pacific Ocean to western coasts of America.'' In the eastern Pacific, this species appears most abundant around the offshore islands. I have examined specimens from the Tres Marias Islands (San Juanito, Maria Madre, Maria Magdalena, and Cleopha), the Revillagigedo Islands (Clarion and Socorro), Clipperton Island, and Cocos Island. I have not verified two records from the Galápagos Islands: Tower Island by Snodgrass and Heller (1905:365), and of the synonymous *C. medusicola* from ''Chatham Islands, as *Caranx latus*'' by Fowler (1938:245). On the western American mainland, I have examined specimens from three localities in Mexico: Cape San Lucas (Baja California Sur), Mazatlán (Sinaloa), and Chacala (Nayarit). Specimens have been reported (as *Caranx stellatus*) from as far south as Panama by Walford (1937: 75). Gilbert and Starks (1904) did not record this species, under the synonymous name of *C. medusicola,* from Panama, as some authors have suggested.

## GEOGRAPHIC VARIATION

In the smaller sizes, eastern Pacific specimens have slightly deeper bodies than those from the Indo-West Pacific. Using the depth measurement of pelvic fin origin to origin of the first dorsal spine, the following approximate percent of standard length values were obtained (* = single specimen):

| mm SL | Eastern Pacific | Indo-West Pacific |
|---|---|---|
| 63–69 | 42* | 37–41 |
| 70–79 | 40–44 | 37–40 |
| 80–99 | 39–43 | 37–38 |
| 100–119 | 38–41 | --- |
| 120–149 | 38–41 | 34–38 |

This was the only character observed that indicated any appreciable variation between fish from the two areas.

## SYNONYMY

I find that three nominal species and possibly three others are junior synonyms of *Caranx melampygus* Cuvier (in Cuvier and Valenciennes, 1833):

*Caranx bixanthopterus* Rüppell 1835,
*Caranx stellatus* Eydoux and Souleyet 1841,
*Caranx medusicola* Jordan and Starks 1895,
?*Caranx punctatus* Quoy and Gaimard 1824,
?*Caranx quoyi* Bleeker 1878,
?*Caranx moresbyensis* Macleay 1883.

When Rüppell (1835: 49) first described *C. bixanthopterus,* he placed the previously named *C. melampygus* in questionable synonymy of his new species. Günther (1876: 133) recorded *C. stellatus* and *C. bixanthopterus* as synonyms of *C. melampygus.* A period of 48 years followed during which the issue was confused, with other specific names being erroneously applied to this species, and culminating in the work of Wakiya (1924: 183–192) in which the above three nominal species were all recorded as distinct. Weber and de Beaufort (1931: 243–253) gave *C. bixanthopterus* as a synonym of *C. melampygus* and distinguished this unspotted form with a higher number of scutes (36–38) from *C. stellatus,* "with irregular dark spots, increasing in number and size with age" and with 30–35 scutes. They also included *C. punctatus, C. quoyi,* and *C. moresbyensis* as junior synonyms of this complex. Nichols (1935: 192) stated that he knew of, "no good technical characters to separate" *C. melampygus* from *C. stellatus.*

Woods (in Schultz *et al.,* 1953: 512), with an adequate size series of specimens, concluded that *C. melampygus* and *C. stellatus* were ontogenetic color stages of the same species—the smaller *C. melampygus* grew into the larger, spotted *C. stellatus.* This was substantiated by Williams (1958: 382) and Lane (MS).

*Caranx moresbyensis* was ascribed to questionable synonymy of *C. melampygus* by McCulloch (1926: 70), who inferred that positive identification could not be made because of discrepancies between the original description by Macleay (1883: 358) and the inadequately designated specimen in the Macleay Museum that McCulloch suspected to be the holotype.

*Caranx coeruleopinnatus* Rüppell 1826 is currently considered to be a junior synonym of *Carangoides malabaricus* (Block and Schneider 1801) (Williams, 1958: 405). Cuvier (in Cuvier and Valenciennes, 1833: 119) described a specimen of *Caranx melampygus* under the name of *Caranx coeruleopinnatus* Rüppell—he did not describe it as a new species as some authors have inferred. Cuvier equated his specimen with *Caranx punctatus* Quoy and Gaimard 1824, and compared it to *Caranx melampygus.* Rüppell (1835: 47) refuted Cuvier's identification. Bleeker (1853: 44) listed the specimen and description of *Caranx coeruleopinnatus* given by Cuvier as differing from the species described by Rüppell, but as synonymous with the *Caranx punctatus* of Quoy and Gaimard. However, later Bleeker (1878: 50) apparently considered the references of both Cuvier and of Quoy and Gaimard to apply to a species for which he proposed the replacement name of *Carangus quoyi.*

*Caranx medusicola* has previously been considered as a distinct species endemic to the eastern Pacific (see Walford, 1937: 72; Lane, MS). It was described from Mazatlan, Mexico, by Jordan and Starks in Jordan *et al.* (1895: 430; pl. 34). The illustration and the major portion of the morphological description were based upon the largest specimen preserved, stated to be 6 inches TL (Figure 1B). Color notes of another specimen were given. Included in the new species account was the brief description of smaller specimens, ". . . very young, taken from the body of a *Medusa.*" The habitat of these smaller specimens stimulated the specific name (*Medusa,* a jellyfish; *colo,* to inhabit.) All of these specimens were included in this series of syntypes at Stanford University Natural History Museum with the collection number 2845 (not 2645 as originally published.) A note in the museum jar inferred that some of the type specimens, presumably the "very young," were sent to museums at London and Vienna.

The series of syntypes of *C. medusicola* remaining at Stanford University contained (in July 1963) two larger specimens (96 and 123 mm SL) and 41 smaller specimens (10.6 to 25.5 mm SL, of which four are cleared and alizarin stained). The largest of these, 123 mm SL, (Figure 1B) is herein designated as the lectotype of *C. medusicola* to retain the original museum number (2845). The lectotype and the 96-mm specimen are conspecific with *C. melampygus;* hence *C. medusicola* is a junior synonym of that name. The 41 smaller specimens are all conspecific with *C. vinctus* Jordan and Gilbert 1881. They have preopercular spines that are atypical of the genus *Caranx* in that the angle spine is not the longest spine in the preopercular complex, and they have different counts of dorsal soft-rays, 23–24, and anal soft-rays, 18–21 (one aberrant specimen with D. 21 and A. 19). The larger specimens of *C. vinctus* in this series have 9–10 + 25–27 gill rakers and 10 + 14 vertebrae.

All other specimens I have seen that had previously been identified as *C. medusicola* are conspecific with *C. melampygus* (SU 180; USNM 125284, 54562; UCLA W58-4; BC 54-64, 60-488). Differences previously ascribed to these two nominal species were either based upon then unrecognized ontogenetic changes or damaged or distorted specimens. This invalidity of *C. medusicola* was first suggested by Mansueti (1963: 55).

## SPECIMENS EXAMINED

Tres Marias Islands, BLLJ B6108-7, B6108-11; BC 59-261, 60-488. Socorro Island, BC 57-152, 59-261; UCLA W55-124; CAS 2446-2448. Clarion Island, SU 180; USNM 54562, 125284; BC 58-383. Clipperton Island, SIO 59-10, 59-9; UCLA W56-238, W58-285, W58-296; CAS W50-291. Cocos Island, SIO 63-252; UCLA W53-135, W58-378; BC 45-403. Mexico, Cape San Lucas, BC 54-64; Mazatlan, SU 2845; Chacala, UCLA W58-4. Hawaii, CAS 1U10442. Tahiti, SIO 61-83. Samoa, CAS uncataloged. New Guinea, USNM 30546. Borneo, USNM 75893. Australia, SIO 61-131. Zanzibar, BLBG uncataloged.

## LITERATURE CITED

Berry, Frederick H. 1959. Young jack crevalles (*Caranx* species) off the southeastern Atlantic coast of the United States. U.S. Fish and Wildl. Serv., **59**(152) : 417–535.

Bleeker, P. 1853. Nalezingen op de ichthyologische fauna van Bengalen en Hindostan. Verh. Bat. Gen., **25** : 1–164.

——— 1878. Quatrième mèmoire sur la fauna ichthyologique de la Nouvelle-Guinée. Neerl. Sc. Nat., Arch., **13** : 35–66.

Bloch, M. E., and Jo. Gottlob Schneider. 1801. Systema ichthyologiae iconibus ex illustratum . . . Berolini, lx + 584 p.

Cuvier, Georges, and Achille Valenciennes. 1833. Histoire naturelle des poissons. Paris, F. G. Levrault, **9** : 1–512.

Eydoux, J. F. T., and F. L. A. Souleyet. 1841. Poissons. *(In)* Bertrand, Arthus, Editeur. Voyage autour du monde exécuté pendant les années 1836 et 1837 sur la corvette la Bonite commandée par M. Vaillant . . . Histoire Naturelle. Zoologie. Paris, Libraire de la Société de Géographie, **1**(2) : 155–216.

Fowler, Henry W. 1938. The fishes of the George Vanderbilt South Pacific Expedition, 1937. Acad. Nat. Sci. Phila., Monogr., no. 2, iii + 349 p.

Gilbert, Charles Henry, and Edwin C. Starks. 1904. The fishes of Panama Bay. Calif. Acad. Sci., Mem., **4** : 1–304.

Günther, Albert C. L. G. 1876. Andrew Garrett's Fische der Südsee. *(V)*. Jour. Mus. Godeffroy, **11** : 129–168.

Jordan, David Starr, Edwin Chapin Starks, George Bliss Culver, and Thomas Marion Williams. 1895. The fishes of Sinaloa. L. Stanford Jr. Univ. Publ., Contr. Biol. Hopkins Lab., 2nd ser., **5**(1) : 377–514.

Lane, E. David. (MS). A review of the genus *Caranx* from the tropical east Pacific. Unpublished thesis, University of British Columbia, Apr. 1962, 77 p.

Macleay, William. 1883. Contribution to a knowledge of the fishes of New Guinea.—No. 2. Linn. Soc. New South Wales, Proc., **7** : 351–366.

McCulloch, Allan R. 1926. Ichthyological items. No. 2. Queensland Mus., Mem., **8**(1) : 61–76.

Mansueti, Romeo. 1963. Symbiotic behavior between small fishes and jellyfishes, with new data on that between the stromateid, *Peprilus alepidotus*, and the scyphomedusa, *Chrysaora quinquecirrha*. Copeia, 1963, (1) : 40–80.

Nichols, J. T. 1935. The Hawaiian "ulua." Copeia, 1935, (4) : 192–193.

Quoy, J. R. C., and P. Gaimard. 1824. Voyage autour du monde . . . execute sur les corvettes de S. M. "L'Uranie" et "La Physicienne" pendant les années 1817–20. Poissons. Paris, chap. 9, p. 192–401.

Rüppell, Edward. 1826. Atlas zu der Reise in nördlichen Afrika. Zoologie. Fische des rothen Meeres. Frankfurt am Main.

——— 1835. Neue Wirbelthiere zu der Fauna von Abyssinien gehörig. Fische des rothen Meeres. Frankfurt am Main, Siegmund Schmerber, 148 p.

Schultz, Leonard P., Earl S. Herald, Ernest A. Lachner, Arthur P. Welander, and Loren P. Woods. 1953. Fishes of the Marshall and Marianas Islands. Vol. I. Families Asymmetrontidae through Siganidae. U.S. Natl. Mus., Bull., (202) : xxxii + 685.

Snodgrass, Robert E., and Edmund Heller. 1905. Papers from the Hopkins-Stanford Galápagos Expedition, 1898–1899. 17. Shore fishes of the Revillagigedo, Clipperton, Cocos and Galápagos Islands. Wash. Acad. Sci., Proc., **6** : 333–427.

Wakiya, Yojiro. 1924. The carangoid fishes of Japan. Carnegie Mus., Ann., **15**(2–3) : 139–292.

Walford, Lionel A. 1937. Marine game fishes of the Pacific coast from Alaska to the Equator. Berkeley, Univ. Calif. Press, xxix + 207 p.

Weber, Max, and L. F. de Beaufort. 1931. The fishes of the Indo-Australian Archipelago. 6. Perciformes (continued) . . . Leiden, E. J. Brill, xii + 488 p.

Williams, F. 1958. Fishes of the family Carangidae in British East African waters. Ann. Mag. Nat. Hist., ser. 13, **1** : 369–430.

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# BIOLOGY AND CHEMISTRY

## FIELD APPLICATION OF METHODS FOR RECOVERY OF THE SELECTIVE LAMPRICIDE, 3-TRIFLUOROMETHYL-4-NITROPHENOL

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*Abstract.* Colorimetric methods are described for the detection of residues of the selective lampricide, 3-trifluoromethyl-4-nitrophenol (TFM), in natural waters and fish tissues. Solvent extraction and anion exchange were used to separate and concentrate the lampricide, and to reduce high background colors which often interfere with the determinations. Data from the Pentwater and Muskegon Rivers (Michigan) showed an exponential rate of disappearance of TFM from the water immediately after treatments to eradicate larvae of the sea lamprey (*Petromyzon marinus*). No TFM was recovered from fish exposed in their natural environment to low levels of the lampricide during treatment; residues were recovered, however, from fish exposed to high concentrations in the laboratory.

### INTRODUCTION

Interest has been growing in the amount of 3-trifluoromethyl-4-nitrophenol (TFM) that might become part of the organic content of natural waters, bottom sediments, and animal tissues from use of this chemical for control of the sea lamprey (*Petromyzon marinus*) in the Great Lakes. The Bureau of Commercial Fisheries Biological Laboratory in Ann Arbor has undertaken a study of the detection and measurement of residues of TFM (Daniels et al. 1963, 1965). The chemical characteristics of TFM have also been described (Daniels et al. 1965).

The colorimetric method of analysis for TFM must be preceded by concentration of the compound to detect the extremely small amounts that might be present. Because high background colors also interfere with the colorimetric analysis, procedures are used to separate the lampricide from other colored compounds. This paper describes the application of these procedures to the analysis of natural waters and fish tissues for TFM residues.

### COLORIMETRIC METHOD

The intense yellow color of basic solutions of TFM forms the basis for the colorimetric technique (Smith, Applegate, and Johnson 1960). TFM, which has a molar absorptivity of 13,400 $cm^2/mol.$, can be determined by direct colorimetric measurement at 395 $m\mu$. These measurements are usually limited to solutions containing more than 0.1 ppm. The minimum level of detectability is influenced, however, by natural color and turbidity of the water (Shapiro 1957, 1958). Measurements of lower concentrations of TFM in natural water are possible after preliminary concentration. Unfortunately, colored compounds other than the lampricide also may be concentrated to such a degree that the resulting background color interferes with the determination. Some method must be used, therefore, to separate the lampricide from the concentrate.

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[1] The first three authors are in the Department of Chemical and Metallurgical Engineering, and the fourth in the Department of Civil Engineering.

A procedure that includes anion exchange and a series of solvent extractions has been employed for the separation and concentration of TFM from natural water (Daniels et al. 1965). Phenolic compounds form negatively charged phenolate ions in basic solution and therefore exhibit exchange properties. Sorption of phenols by anion-exchange resins has been reported (Chasanov, Kunin, and McGarvey 1956), and p-nitrophenol has been observed to exchange (Anderson and Hansen 1955). The potassium salt of TFM is quantitatively adsorbed by anion-exchange resins (Daniels et al. 1965).

Preliminary filtration of water samples is often required to remove suspended solids that may clog anion-exchange columns. Adjustment of the pH to 8.5 with potassium hydroxide is necessary to extract TFM by anion exchange. This adjustment often produces additional particulate matter, principally ferric hydroxide and calcium carbonate. Some naturally occurring organic material may also be coagulated. These precipitates are removed by passing the water, after pH adjustment, through microporous filters such as the Millipore HA or Gelman G-5 (0.45 $\mu$ pore size). The amount of TFM lost by adsorption on the solids collected on the filters is assumed to be negligible because of the prevailing negative electrical charge of the filters.

After filtration, measured volumes of the samples were passed through 1-gram beds of an anion-exchange resin (Dowex, 1 x 8, 200-400 mesh resin in the hydroxide form). TFM was subsequently eluted from the resin with amyl acetate, acidified with 3% acetic acid by volume. Naturally occurring compounds left a layer of light-brown material on the resin. The lampricide was then extracted from the amyl acetate with water made basic with potassium hydroxide. The aqueous solution was then made up to a known volume and the TFM concentration measured colorimetrically.

A suitable technique for the recovery of lampricide bound in fish tissues or botton sediments requires that the TFM first be released in a soluble form that can be separated from other colored components. The scheme shown in Figure 1 has been developed for the recovery of TFM from fish tissue; it can also be applied to bottom sediments. This procedure is a modified version of one presented by Daniels et al. (1965).

Anion-exchange and classical solvent-extraction methods are used in the scheme. The anion-exchange step is similar to the one applied to natural waters. Solvent extraction is evaluated by use of a distribution ratio defined here as the ratio of TFM present in each phase of a 2-phase system. The distribution ratio for TFM between polar and nonpolar solvents is dependent upon the pH of the system. Under acidic conditions below its $pK_a$ of 6.07, the lampricide exists principally in its nonionized form, and the distribution ratio favors the organic solvent. Alternatively, TFM will be soluble in water under basic conditions due to its now ionized form. Use of this extraction principle permits both separation and concentration to a point where direct colorimetric analysis can be used to measure the amount of TFM residue.

## RECOVERY OF TFM FROM NATURAL WATERS

Analyses for TFM residues were made before, during, and after treatment of the Pentwater and Muskegon Rivers (Michigan). A preliminary study to test the methods was made on the Pentwater River (Table 1). The river was treated for 12 hours on April 17, 1964, with 3,480 pounds of technical-grade TFM (33.2% active ingredient as its sodium salt). The flow at the

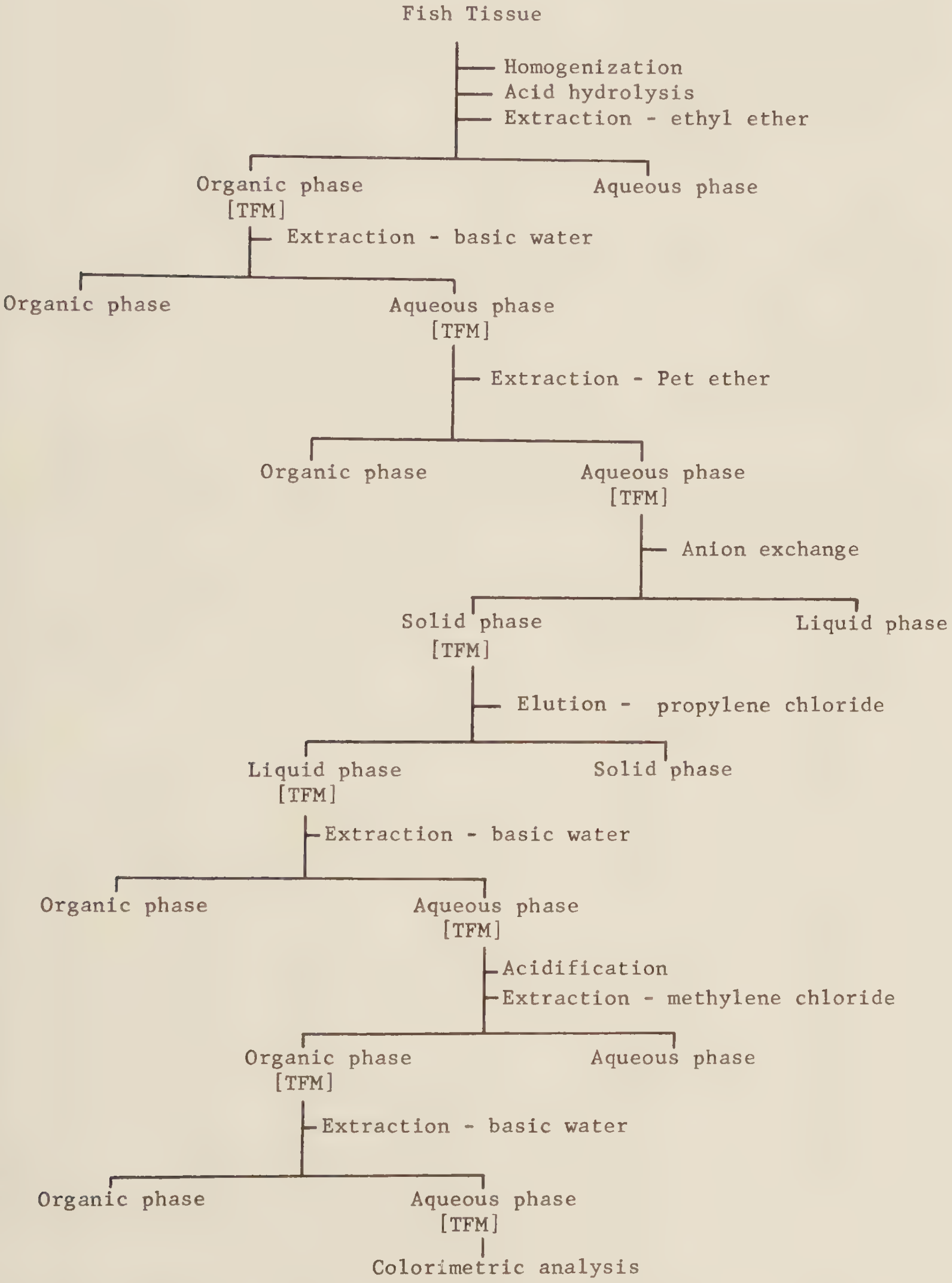
Fish Tissue
Homogenization
Acid hydrolysis
Extraction - ethyl ether
Organic phase [TFM]
Aqueous phase
Extraction - basic water
Organic phase
Aqueous phase [TFM]
Extraction - Pet ether
Organic phase
Aqueous phase [TFM]
Anion exchange
Solid phase [TFM]
Liquid phase
Elution - propylene chloride
Liquid phase [TFM]
Solid phase
Extraction - basic water
Organic phase
Aqueous phase [TFM]
Acidification
Extraction - methylene chloride
Organic phase [TFM]
Aqueous phase
Extraction - basic water
Organic phase
Aqueous phase [TFM]
Colorimetric analysis

FIG. 1. Procedure for separation and concentration of TFM in fish tissues or bottom sediments (modified from Daniels et al., 1965).

TABLE 1. Amounts of TFM detected in water samples from the Pentwater River after treatment for sea lamprey control.[1]
[Sampling site: above Pentwater Lake, T16N, R18W, S24, Oceana County, Michigan]

| Date (1964) | Days after treatment | Before concentration | | After concentration | |
|---|---|---|---|---|---|
| | | Absorbance[2] | Amount (ppm)[3] | Absorbance[2,4] | Amount (ppm)[3] |
| April 17 | 0 | 0.078 | 1.310 | 0.0629 | 1.0600 |
| April 20 | 3 | 0.003 | 0.050 | 0.0002 | 0.0037 |
| August 20 | 122 | 0.000 | 0.000 | 0.0000 | 0.0000 |

[1] Averages of two determinations except day 122.

[2] Absorbance measured at 395 mμ blanked against sample taken 1 day before treatment commenced.

[3] Equivalent concentration of technical-grade TFM in ppm based on a molar absorptivity of 12,300 $cm^2$/mol.

[4] Absorbance corrected for tenfold concentration by anion exchange.

TABLE 2. Amounts of TFM detected in water samples collected from the Muskegon River at different times during and after treatment for sea lamprey control.
[Sampling site: near Bridgeton, T11N, R14W, S14, Newaygo County, Michigan. Numbers in parentheses refer to concentration factor. Treatment began at 1530, October 4, and ended at 0330, October 5]

| Date (1964) and time | Time from end of treatment (hours:minutes) | Before concentration | | After concentration | |
|---|---|---|---|---|---|
| | | Absorbance[1] | Amount[2] (ppm) | Absorbance[1] | Amount[2] (ppm) |
| October 4 | | | | | |
| 2245 | -04:45 | 0.532 | 9.20 | ... | ... |
| 2345 | -03:45 | 0.520 | 9.00 | ... | ... |
| October 5 | | | | | |
| 0055 | -02:35 | 0.542 | 9.40 | 0.484 (10) | 8.38 |
| 0155 | -01:35 | 0.530 | 9.20 | ... | ... |
| 0245 | -00:45 | 0.541 | 9.35 | ... | ... |
| 0330 | 00:00 | 0.507 | 8.77 | 0.396 (10) | 6.85 |
| 0400 | 00:30 | 0.426 | 7.40 | 0.421 (10) | 7.30 |
| 0430 | 01:00 | 0.332 | 5.75 | ... | ... |
| 0500 | 01:30 | 0.247 | 4.30 | 0.232 (10) | 4.02 |
| 0530 | 02:00 | 0.176 | 3.05 | 0.146 (10) | 2.53 |
| 0600 | 02:30 | 0.109 | 1.90 | ... | ... |
| 0630 | 03:00 | 0.091 | 1.58 | 0.075 (10) | 1.30 |
| 0700 | 03:30 | 0.057 | 1.00 | 0.051 (10) | 0.90 |
| 0730 | 04:00 | 0.021 | 0.38 | ... | ... |
| 0800 | 04:30 | 0.027 | 0.47 | 0.0196 (10) | 0.30 |
| 0900 | 05:30 | 0.008 | 0.15 | ... | ... |
| 1000 | 06:30 | 0.000 | 0.00 | 0.0030 (20) | 0.055 |
| 1100 | 07:30 | 0.016 | 0.30 | 0.0025 (20) | 0.025 |
| 1200 | 08:30 | 0.000 | 0.00 | ... | ... |
| 1300 | 09:30 | 0.004 | 0.07 | 0.0013 (20) | 0.010 |
| 1400 | 10:30 | 0.009 | 0.15 | 0.0017 (20) | 0.015 |
| 1500 | 11:30 | 0.002 | 0.02 | 0.0017 (20) | 0.015 |
| 1800 | 14:30 | 0.000 | 0.00 | 0.0006 (40) | 0.005 |
| October 6 | | | | | |
| 0100 | 21:30 | 0.002 | 0.02 | 0.0003 (40) | 0.003 |
| 0800 | 29:30 | 0.001 | 0.01 | 0.0006 (40) | 0.005 |

[1] Absorbance measured at 395 mμ blanked against sample taken 1 day before treatment.

[2] Equivalent concentration of technical-grade TFM in ppm based on a molar absorptivity of 12,300 $cm^2$/mol.

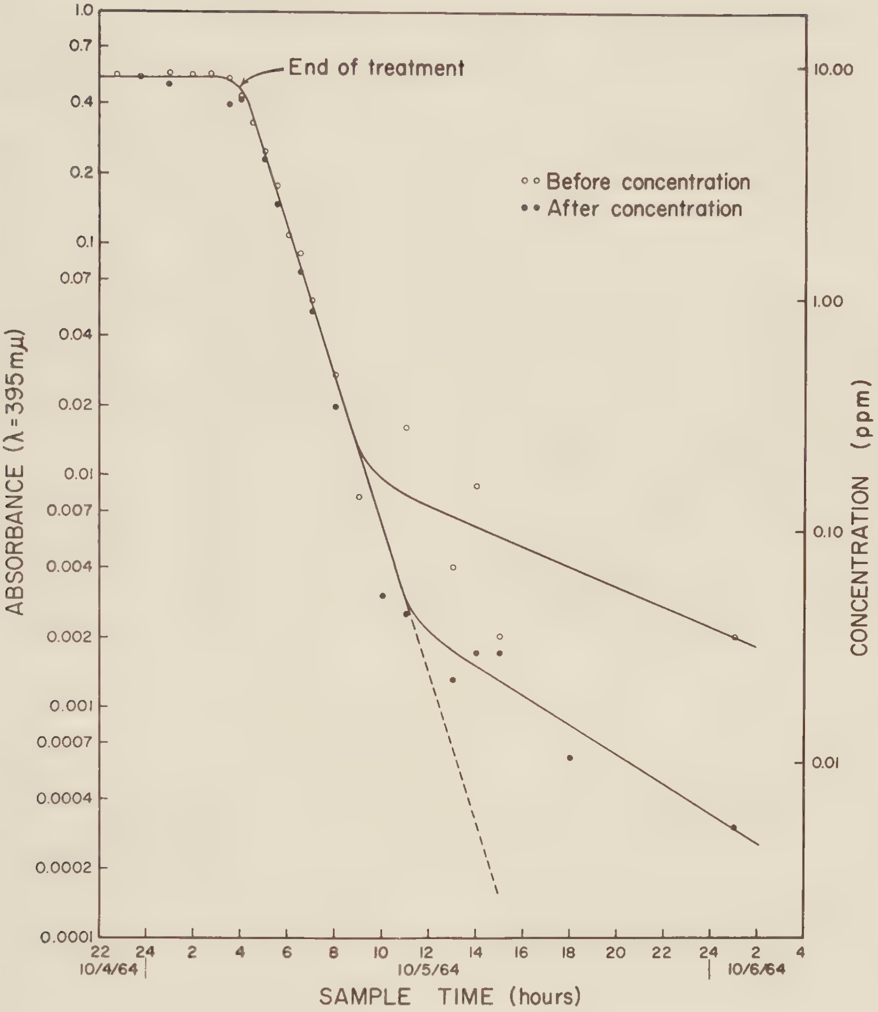

FIG. 2. A plot of the logarithm of absorbance versus time, illustrating the first order disappearance of TFM from the Muskegon River after treatment.

sampling point above Pentwater Lake was 93 cfs. The minimum effective concentration required to kill sea lamprey ammocetes and maximum allowable concentration that would not harm other fish were 2 and 6 ppm, respectively. (The dilution of the treated water with water from an untreated branch of the river, before it had reached the sampling point, reduced the concentration of TFM below 2 ppm in the sample of April 17.)

Two conclusions resulted from this study: 1) assuming that the increase in color, measured after treatment had started, was entirely due to TFM, approximately 80% of the lampricide was recovered by the ion-exchange method; and 2) the concentration of TFM decreased rapidly after treatment (Table 1). The TFM had almost disappeared by April 20 (3 days after treatment), and no lampricide could be detected 122 days after treatment. The small absorbance reading on April 20 may not have been an accurate measure of residual TFM, as it could have been influenced by variations in the background color or instrumental changes. The amount of TFM was increased to 10 times its original level with the ion-exchange method.

The abrupt depletion of TFM after treatment was investigated in more detail on the Muskegon River on November 4-5, 1964. This river was treated with 78,100 pounds of technical-grade TFM within the maximum allowable concentration of 15 ppm and the minimum effective level of 6 ppm, for 12 hours. The amount of TFM in the water samples, taken at frequent intervals, was measured directly after pH adjustment, and again after filtration and recovery by the anion-exchange procedure (Table 2).

A plot of the logarithm of absorbance versus time yielded a straight line; the disapparance of TFM thus follows first order kinetics, assuming a constant stream flow (Fig. 2). Three samples taken more than 8 hours after treatment ended had zero absorbance before concentration. Values for the amount of TFM measured after concentration were more consistent than those measured before concentration at the lower absorbances. The scattering of the data at the lower values can be attributed to a number of factors: 1) possible fluctuations of temperature, dissolved oxygen, and pH which could cause desorption of TFM from the bottom sediments; 2) fluctuations in the flow rate; 3) the intermittent flushing of TFM trapped in pools, eddies, and backwaters; and 4) instrumental limitations at low levels. TFM values dropped from approximately 9 ppm at the conclusion of treatment to less than 0.2 ppm in 6 hours and less than 0.02 ppm (0.5% of treatment level) after 8 hours.

## RECOVERY OF TFM FROM FISH

The amount of lampricide recoverable from fish by the modified scheme was determined by adding 300 micrograms of TFM to aliquots (about 50 grams) of homogenized tissue of the alewife (*Alosa pseudoharengus*). An average of 71.5% of the TFM was recovered in the final basic water solutions (Table 3). Extraction was not exhaustive, which may have contributed to the apparent loss of TFM. Equal amounts of fish tissue, to which no TFM was added, were carried through the recovery process to provide blank solutions for the colorimetric analysis.

The success of this procedure led to attempts to recover TFM from fish that had lived in water containing lampricide. Fingerling rainbow trout (*Salmo gairdneri*) exposed to 2 to 4 ppm TFM for 1 to 7 days in raceway tests at the Hammond Bay Biological Station, and various other species of fish exposed to TFM during stream treatment, were analyzed. No TFM residues were recovered.

TABLE 3. Amount of TFM recovered after addition to alewife tissue.

| Experiment | TFM added (μg) | TFM recovered (μg) | Percentage recovery |
|---|---|---|---|
| A | 300 | 226 | 75.3 |
| B | 300 | 198 | 66.0 |
| C | 300 | 214.5 | 73.3 |
| Average | ... | ... | 71.5 |

These negative findings were explored further by laboratory experiments in which green sunfish (*Lepomis cyanellus*) were used. The fish were exposed to high levels of TFM under carefully controlled conditions. Since metabolism or enzymatic degradation of TFM may occur soon after death, it is preferable to remove the fish from the test solution just before death, wash them with distilled water to remove clinging droplets of the test solution, and immediately homogenize them with concentrated hydrochloric acid. This treatment should prevent degradation of TFM after death. Various amounts of TFM residues were recovered (Table 4).

TABLE 4. Amounts of TFM recovered from green sunfish exposed to high concentrations under controlled laboratory conditions.

| Experiment | Exposure time (hours) | Concentration of solution (ppm) | Total weight of fish used (grams) | Elution solvent[1] | Other comments | Total TFM recovered (μ grams) |
|---|---|---|---|---|---|---|
| A-1 | 43.0 | 86.4 | Not weighed | Amyl acetate | Fish remained in TFM solution for unknown time after death | 12 |
| A-2 | 40.0 | 78.0 | do | do | do | 39 |
| B-1 | 3.8 | 50.0 | 68.6 | Propylene dichloride | Fish removed before death and homogenized in acid immediately | 28 |
| B-2 | 0.5 | 20.0 | 50.0 | do | do | 20 |
| B-3 | ... | ... | 52.1 | do | 500 μg TFM added to fish tissue after homogenization in acid | 300 |

[1] Solvent used to elute TFM from anion-exchange resin.

In experiments A-1 and A-2 the fish died during the night and remained in the TFM solution for an unknown amount of time after death. Experiment B-3 was a check of the recovery scheme with propylene dichloride (1,2-dichloropropane) as the elution solvent instead of amyl acetate, and was similar to the experiments shown in Table 3; approximately 60% of the TFM was recovered. Recoveries in experiments A-1 and A-2 were probably low because degradation may have occurred, and because amyl acetate was used as the elution solvent (propylene dichloride gives more consistent TFM recoveries).

In these experiments in which fish were exposed to high concentrations of TFM, a different procedure was used to calculate the amount of lampricide recovered. The absorbance was recorded at various wavelengths near the absorption maximum of TFM. From these data a spectrophotometric curve was plotted on transparent graph paper with the logarithm of the absorbance and the corresponding wavelength as the ordinate and abscissa, respectively. Straight lines were obtained from analysis of blank solutions and similar straight lines, except for a protuberance at 395 mμ, were obtained from the test solutions. If it is assumed that the compounds contributing to the background color were present in the same ratio in each solution, and varied only in the total amount present, the only difference in the shape of these curves when superimposed (test solution on its corresponding blank solution) should then be due to TFM (Mellon 1950). The amount of TFM was determined by measuring the distance between the curves at 395 mμ when they were superimposed, and making the appropriate conversions. The effects of small variations in background color were eliminated by this technique.

## LITERATURE CITED

ANDERSON, R. E., and R. D. HANSEN. 1955. Phenol sorption on ion exchange resins. Ind. Eng. Chem. 47: 71-75.

CHASANOV, M. G., R. KUNIN, and F. McGARVEY. 1956. Sorption of phenols by anion exchange. Ind. Eng. Chem. 48: 303-309.

DANIELS, S. L., L. L. KEMPE, E. S. GRAHAM, and A. M. BEETON. 1963. Quantitation of microorganic compounds in waters of the Great Lakes by adsorption on activated carbon. Great Lakes Res. Div., Inst. Sci. Tech., Univ. of Mich., Pub. No. 10, p. 118-123.

__________, __________, T. J. BILLY, and A. M. BEETON. 1965. Detection and measurement of organic lampricide residues. Great Lakes Fishery Commission Tech. Rept. No. 9, 18 p.

MELLON, M. G. 1950. Analytical absorption spectroscopy. John Wiley and Sons, Inc., New York. 1st ed., p. 306-341.

SHAPIRO, JOSEPH. 1957. Chemical and biological studies on the yellow organic acids of lake water. Limnol. Oceanogr. 2: 161-179.

__________. 1958. Yellow acid cation complexes in lake water. Science 127: 702-704.

SMITH, MANNING A., VERNON C. APPLEGATE, and B. G. H. JOHNSON. 1960. Colorimetric determination of halogenated nitrophenols added to streams as sea lamprey larvicides. Anal. Chem. 32: 1670-1676.

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Chesapeake Science Vol. 6, No. 3, pp. 197–198 September, 1965

# Observation on Tag Loss and Comparative Mortality in Striped Bass

**Chesapeake Science Vol. 6, No. 3, pp. 197–198 September, 1965**

# Observation on Tag Loss and Comparative Mortality in Striped Bass

This note presents observations made of 41 tagged and 39 untagged striped bass, *Roccus saxatilis.* The 80 fish were held in a concrete, saltwater pond for a two-week acclimation period before tagging, and then observations were continued for an additional eight weeks. The study was made to observe tag loss of Atkins-type streamer tags and comparative mortality of tagged and untagged fish.

Fish used in the study were obtained from pound nets in Albemarle Sound, N. C., in April 1962, and transported by tank truck to the Bureau of Commercial Fisheries Biological Laboratory at Beaufort, N. C., a distance of 150 miles (Bonner, 1963). The fish ranged in size from 14.2 to 15.8 inches fork length. Before release into the pond, the fish were held in a 1:10,000 solution of malachite green for 2½ minutes to inhibit fungus infection. While held captive, the striped bass were fed a daily diet of small live fish seined from tidal waters around the laboratory.

The holding pond was 42 feet wide by 47 feet long, 6 inches deep at the shallow end, sloping to 4 feet at the deep end. At the deep end an 8-x-8-foot piece of plywood provided some shade for the fish. Salt water was supplied continuously at the rate of 50 gallons per minute. Constant water depth was maintained by an overflow standpipe. Average weekly water temperatures ranged from 17.5°–27.8° C; dissolved oxygen concentrations from 6.2–10.8 ppm; and salinity from 28.7–33.9‰ (Fig. 1).

After two weeks' acclimation, all fish were seined and 41 of those were dip-netted and tagged. The tags used were yellow laminated plastic pennants tied to nylon loops and were affixed under the second dorsal fin near the base, allowing the pennants to trail over the caudal peduncle.

Water transparency and pool depth permitted visual observation of the fish behavior and external appearance throughout the experiment. After tagging, the following observations were made: (1) Throughout the first six weeks, tagged and untagged fish appeared energetic and fed vigorously when food was introduced. The presence of the tag did not appear to influence the behavior or feeding habits of the fish. (2) In the fifth week, algae (*Enteromorpha* and *Polysephonia*) appeared on several tags. At that time, average water temperature was 24.0° C, and average salinity was 28.7‰. (3) In the sixth week, heavy accumulations of algae appeared on all tags (Fig. 2). Average water temperature increased to 26.8° C and average salinity to 32.8‰. (4) In the seventh week, fish became less active, and their feeding activity greatly reduced. Average water temperature was 27.0° C, and average salinity was 33.1‰. (5) In the eighth week, 10 (24%) tagged fish and 15 (38%) untagged fish died, and 9 (22%) tags were shed, including 5 from fish that subsequently died. Average water temperature was 27.8° C, and average salinity was 33.9‰.

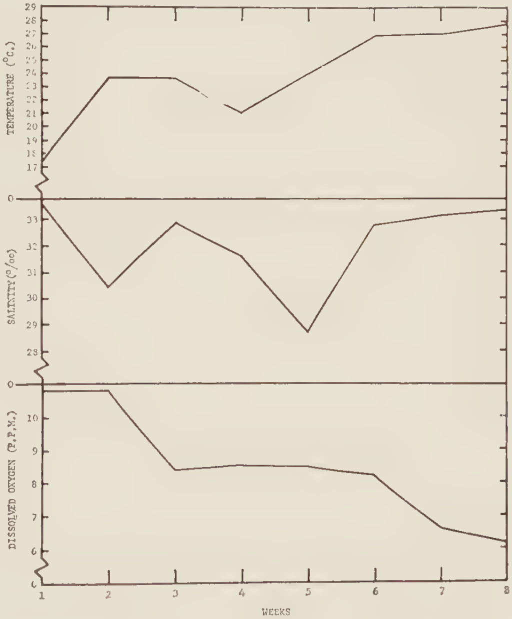

Fig. 1. Average weekly water temperature, salinity, and dissolved oxygen in experimental pond.

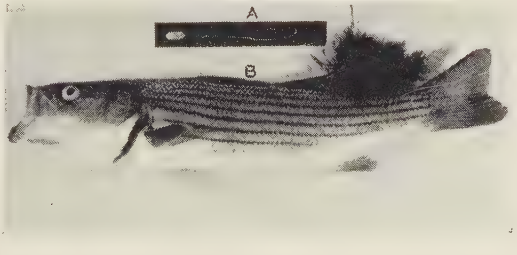

Fig. 2. Atkins-type streamer tag and accumulation of algae on tag affixed on striped bass for eight weeks.

Chadwick (1963) tested streamer tags on striped bass in California waters and reported that they were satisfactory for mark-recapture studies over a nine-month period. Davis (1956) and Mansueti (1956) observed accumulations of plant and animal growth on tags attached to striped bass more than 300 days, but the accumulations were much less dense than those observed in the present study. Lewis (1961) observed a marine growth on streamer tags which were attached to striped bass more than one year prior to recapture and reported that infected tagging wounds were rare.

In the present study, the causes of tag loss and mortality in tagged and untagged fish were not completely known. The extensive accumulation of algae on the tags caused severe irritation at the point where the nylon loop passed through the flesh, and probably was the primary factor contributing to tag loss. The water temperature in the pond exceeded that found normally in the natural habitat, and during the last two weeks of the experiment, the fish took little food, which may have contributed to mortality. However, observations indicated that loss of Atkins-type streamer tags, by either shedding or fish mortality, was negligible for the first six weeks after tagging.

## LITERATURE CITED

Bonner, R. R., Jr. 1963. A method of transporting striped bass. *Prog. Fish-Cult.* 25(4):217.

Chadwick, H. K. 1963. An evaluation of five tag types used in a striped bass mortality rate and migration study. *Calif. Fish and Game*, 49(2):64–83.

Davis, W. S. 1959. Field tests of Petersen, streamer, and spaghetti tags on striped bass, *Roccus saxatilis* (Walbaum). *Trans. Am. Fish. Soc.* 88(4):319–329.

Lewis, R. M. 1961. Comparison of three tags on striped bass in Chesapeake Bay area. *Ches. Sci.* 2(1–2):3–8.

Mansueti, R. J. 1956. Recaptures of tagged striped bass, *Roccus saxatilis* (Walbaum), caught in deep water of Chesapeake Bay, Maryland. *Md. Dept. Research and Educ. Resource Study Rept.* (10):1–9.

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# A New Mollusk (Bivalvia, Erycinidae) Commensal on the Stomatopod Crustacean *Lysiosquilla*

BY KENNETH J. BOSS[1]

## INTRODUCTION

Certain small bivalve mollusks, most frequently members of the eulamellibranch superfamily Erycinacea, are often associated with other marine invertebrates as parasites, symbionts, or commensals. Pelseneer (1935) and Caullery (1952) have listed numerous leptonids, erycinids, galeommatids, and montacutids which live in or attached to coelenterates, sipunculids, crustaceans, echinoids, holothurians, or mollusks. In North America known examples of these interrelationships include: *Rochefortia cuneata* in association with the sipunculid worm *Phascolion strombi*, in the empty shells of *Nassarius trivittatus* or *Eupleura caudata* (Hampson, 1964); *Rochefortia* sp. commensal on specimens of the large sand crab *Blepharipoda occidentalis* (Burch and Burch, 1944; Emerson, 1944); *Serridens oblonga* on the chiton *Ischnochiton heathiana* (Smith and Gordon, 1948); and *Pseudopythina rugifera* attached to the blue mud shrimp, *Upogebia pugetensis* (Dall, 1899), or, even more frequently, to the sea mouse *Aphrodite* (MacGinitie and MacGinitie, 1949).

From the burrows of the stomatopod crustacean *Lysiosquilla maculata* in Australia, Popham (1939) has described the commensal galeommatid

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*Phlyctaenachlamys lysiosquillina*, and Powell (*in* Morton, 1957) has suggested that the small New Zealand bivalve *Divariscintilla maoria* may live associated or attached to *Lysiosquilla*. Holthuis (1951) has reviewed the taxonomy and literature on the small lamellariid gastropod *Caledoniella montrouzieri*, which is known to associate with the stomatopod *Gonodactylus chiragra*.

During the preparation of a revision of the Stomatopoda, Dr. Raymond Manning of the United States National Museum of the Smithsonian Institution noted several specimens of a small, attached bivalve on a specimen of the Caribbean *Lysiosquilla scabricauda* (Lamarck) in the collection of the American Museum of Natural History. This discovery constituted the first documented occurrence of a commensal lamellibranch attached to the ventral surface of the abdomen and thorax of a stomatopod and, on close examination, the small bivalve proved to be a new genus and species.

## **PARABORNIA,** NEW GENUS[1]

TYPE SPECIES, HERE DESIGNATED: *Parabornia squillina* Boss, new species.

DESCRIPTION: Shell small, with a weak amphidetic external ligament and a developed, central, internal resilium, which lacks a lithodesma. Dentition consisting of two small dentiform processes on each side of resilium; denticles of right valve interlocking between those of left valve. Narrow, ventral, pedal-byssal gape and obsolete anterior and posterior gapes. Mantle papillose, with slitlike posterior and broad anteroventral openings. Both ctenidia with complete inner and outer demibranchs. Foot divided into anterior pedal and posterior byssal portions. Full complement of adductor and pedal-byssal musculature developed. Sex and incubatory behavior unknown.

### **Parabornia squillina,** new species

Figures 1–3

DESCRIPTION: Shell small, extending to less than 7 mm. in length and to less than 5 mm. in height, compressed, lentiform, equivalved, inequilateral, thin, fragile, subtransparent, and whitish. Umbos anterior to middle, elevated, inflated, prosogyrous, and with a moderately extensive internal cavity. Anterior portion of shell shorter than posterior. All margins smoothly convex; anterior margin broadly rounded; posterior margin somewhat narrowly round and pointed. Appressed valves with a narrow, ventral, pedal-byssal gape and obsolete anterior and posterior gapes. Shell sculptureless, with faint, microscopic, subreniform, concentric lines of growth evident in transmitted light. No true lunule or escutcheon. Adductor, pedal, or pallial muscle scars not impressed or visible. Hinge line gently convex, consisting of a weak, obsolete, amphidetic, external ligament and a developed, buttressed, internal resilium without a lithodesma. Dentition weak, centralized, subumbonal, and consisting of two small teeth or denticles in both valves; resilium uniting valves between paired teeth. Right denticles somewhat pointed, narrowly divergent, and interlocking between blunt, more widely divergent left denticles. Mantle united dorsally, posteriorly, and posteroventrally but with a single, posterior, anal, or exhalant slit and an anteroventral pedal-byssal and inhalant opening. Mantle edge with numerous papillae which are differentiated anteriorly into three tentaculate structures but not differentiated posteriorly. Mantle capable of complete retraction into shell cavity. Ctenidia consisting of two laterally paired demibranchs with ascending and descending lamellae, the external demibranch smaller. Foot terete in section, weakly grooved, plantar, and with a well-developed byssal gland posteriorly. Anterior and posterior adductor muscles subequal in size; anterior and posterior pedal retractors dorsal to adductors. Sex and incubatory behavior, if any, unknown.

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[1] This generic name is feminine and is compounded of *Bornia* Philippi and the prefix "para," meaning "alongside."

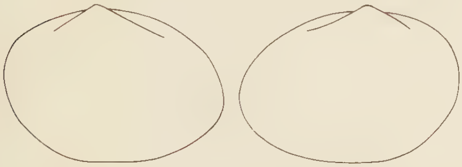

FIG. 1. Outline of the external surface of the shell of *Parabornia squillina*, new species. *Left:* Left valve. *Right:* Right valve. Length of specimen, 5.9 mm.

| LENGTH | HEIGHT | WIDTH | |
|---|---|---|---|
| 5.9 mm. | 4.2 mm. | 1.8 mm. | Holotype |
| 6.3 | 4.5 | 2.0 | Paratype |
| 6.2 | 4.3 | — | Paratype |
| 6.1 | 4.2 | 1.8 | Paratype |
| 6.0 | 4.2 | 1.8 | Paratype |
| 6.0 | 4.2 | 1.8 | Paratype |
| 5.8 | 4.2 | 1.8 | Paratype |
| 5.7 | 4.2 | 1.8 | Paratype |
| 5.6 | 3.9 | — | Paratype |
| 4.7 | 3.6 | 1.4 | Paratype |
| 4.5 | 3.1 | 1.4 | Paratype |

TYPES: The holotype (A.M.N.H. No. 112526) is preserved in the

Department of Living Invertebrates in the American Museum of Natural History. Eight paratypes (A.M.N.H. No. 112527) are also deposited in the American Museum. Two paratypes (U.S.N.M. No. 653701) are deposited in the United States National Museum of the Smithsonian Institution.

Type Locality: The type locality is Cristobal, Canal Zone, Panama. The specimens were collected on August 23, 1934, attached to the ventral surface of the abdomen and thorax of *Lysiosquilla scabricauda* (Lamarck).

Anatomical Remarks (see fig. 3): The mantle has two openings, a small posterior exhalant slit and an extensive anteroventral gape which is functionally a pedal, byssal, and anterior inhalant opening. The inner lobes of the mantle fuse ventrally just posterior to the position of the byssus and anterodorsally in the vicinity of the anterior adductor muscle. There are three mantle lobes: a thin outer lobe which secretes the periostracum and lies next to the inner surface of the shell at its edge; a middle, thickened, muscular lobe; and a thin inner lobe which is fused along much of its extent and which bears numerous papillae on its outer surface. The papillae extend completely around the margin of the mantle, even dorsally where they are small. Anteriorly, just at the fusion of the inner lobe of the mantle near the anterior adductor muscle, there are three pairs of differentiated, enlarged, elongate papillae or "tentacles." There are no other differentiated papillae.

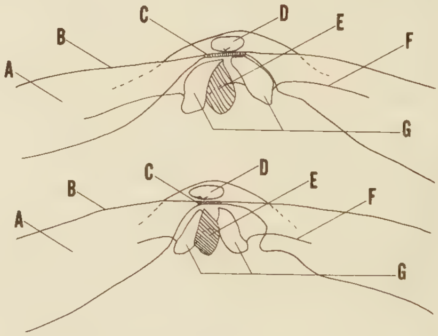

Fig. 2. Hinge of *Parabornia squillina*, new species. *Top:* Left valve. *Bottom:* Right valve. Length of area illustrated, about 2 mm.

*Symbols:* A, reflected portion of the periostracum; B, edge of the shell; C, obsolete external ligament; D, umbo; E, internal resilium; F, lateral buttress of the hinge plate; G, denticles.

The foot is elongate, bluntly pointed anteriorly, and broadly terete in cross section. Its ventral surface is lightly grooved in the anteroposterior plane. The extensive and well-developed byssal gland and groove occupy the posterior portion of the foot.

The ctenidia consist of two pairs of demibranchs which are united posteriorly behind the foot. Both demibranchs have ascending and descending lamellae, and the gill filaments are numerous and lack inter-

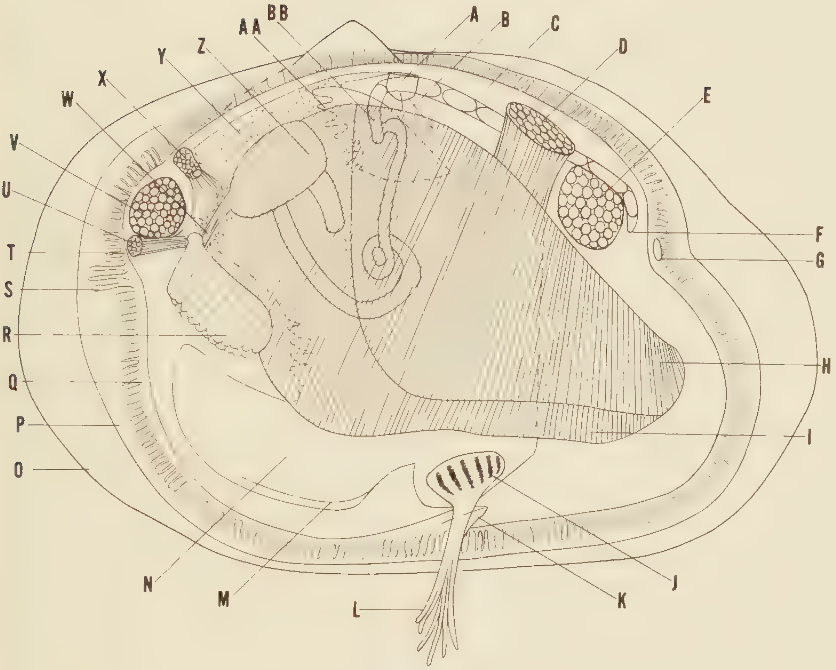

FIG. 3. Semidiagrammatic illustration of the anatomy of *Parabornia squillina*, new species. Specimen with the left valve removed to show general structural features. Length of specimen, about 6 mm.

*Symbols:* A, ventricle; B, auricle; C, rectum; D, posterior pedal-byssal retractor muscle; E, posterior adductor muscle; F, anus; G, exhalant slit; H, outer demibranch; I, inner demibranch; J, byssal gland; K, ventral union of the inner lobes of the mantle; L, byssus; M, pedal groove; N, foot; O, outer lobe of the mantle; P, muscular lobe of the mantle; Q, inner lobe of the mantle, with papillae; R, labial palp; S, differentiated papillae; T, anterior union of inner lobes of the mantle; U, anterior pedal protractor muscle; V, anterior adductor muscle; W, esophagus; X, anterior pedal retractor muscle; Y, digestive gland; Z, stomach, with the style sac; AA, gonad; BB, intestine.

filamentar junctions. The inner demibranch is more extensive than the small and somewhat reduced outer demibranch. There are two pairs of moderately sized, rectangularly shaped labial palps which are fused anteriorly to form the lips of the mouth. The anterior ventral edge of the inner demibranch lies between the inner and outer palps in a position similar to that figured by Popham (1939) for *Kellia suborbicularis*.

The muscular system is well developed and isomyarian. The posterior adductor is broadly sublunate, while the anterior adductor is subtrigonal.

A strong posterior pedal-byssal retractor muscle inserts on the shell just anterodorsal to the posterior adductor, while a smaller anterior pedal retractor attaches just posterodorsal to the anterior adductor. The small, thin, pedal protractor arises ventral to the anterior adductor. The muscle system of *Parabornia* is similar to that of *Bornia* as described by Deroux (1961).

The alimentary canal consists of a slitlike mouth, a rather elongate esophagus, a large stomach, with a posteriorly extending style sac surrounded by the digestive gland, a doubly looped intestine which is not united with the style sac, a rectum which traverses the heart, and an anus which terminates just dorsal to the exhalant opening. Fecal pellets are contained in the rectum. The kidney lies between the heart and the posterior adductor muscle and is traversed by the posterior pedal-byssal retractor muscle. The heart is enclosed in an extensive pericardial cavity; the auricles are paired, transparent, and oblique; the ventricle surrounds the rectum, and a dorsal aorta extends anteriorly. No definitive pericardial gland was observed. The glandular, tubulous, and white gonad is anteroventral to the pericardial cavity and covers a portion of the intestinal tract. It is probable that the specimens dissected were males, in which case the species would be dioecious, but for lack of positive evidence it is not possible to say whether the species is monoecious or dioecious. Likewise it is impossible to say whether the species is incubatory. Although no young were found in the mantle cavity, reproduction could occur at a time other than when the specimens were collected.

A developed cerebropleural ganglion is situated near the posteroventral surface of the anterior adductor muscle, and a bilobular visceral ganglion is between the pedal-byssal retractor and the anteroventral surface of the posterior adductor muscle; the pedal ganglia were not observed.

DISCUSSION OF SYSTEMATIC PLACEMENT: The relationship of *Parabornia* to other small commensal bivalves is not easily determined. Convergence and parallelism in morphological traits, both anatomical and conchological, contribute significantly to the difficulty of discerning a natural taxonomic system which reflects the phylogeny of the group. Dall (1900) and Cossmann and Peyrot (1912) presented critical discussions of the numerous generic and subgeneric divisions based primarily on the characteristics of the hinge and dentition. Pelseneer (1909, 1911, 1925) differentiated the families of these specialized bivalves, indicated the relative positions of genera, and showed where some convergence of types existed. Essentially Thiele (1935) and Popham (1939, 1940) followed Pelseneer in their discussions of the anatomical characteristics of certain families, and Kautsky (1939) based his classification on the outline of

Thiele. More recently, Chavan (1960) has presented a critical discussion of the hinge mechanisms of these mollusks and has discerned six families in the Erycinacea.

To identify the relative taxonomic position of *Parabornia*, an approach that combined the conchological data of Chavan (1960) and the anatomical detail of Pelseneer (1911) and Thiele (1935) was employed. The dentition of *Parabornia* (fig. 2) consists of a central hinge plate with subtending, thin, lateral buttresses. The hinge plate itself supports the internal ligamental element or resilium. On each side of the internal ligament there are small protuberant denticles. In the right valve, the denticles are narrowly divergent and rather pointed, with a tendency to become somewhat lobate distally. In the left valve, the denticles are blunt, oblong, and more widely divergent. The denticles of the right valve interlock between those of the left valve, and the resilium connects the valves within the area of the denticles of the right valve. Such a dental configuration falls within Chavan's "*lucinoide ancien*" type, exemplified by the family Montacutidae. Chavan included within this family a typical group that has only lateral lamellae, represented by *Montacuta* and *Devonia*, another group with short, dentiform lamellae, with *Tellimya*, *Pythinella*, *Laubriereia*, *Lasaeonaera*, *Rochefortula*, and a third group with *Kelliopsis*, *Orobitella*, and *Decipula* which has the anterior lamella coiled up at its extremity, producing a non-detached, toothlike structure. Additionally, *Kona*, *Makinasia*, and *Mysella* are related to the third group. *Parabornia* appears to be most similar to the group represented by *Tellimya*, that is to say, the division that has short, dentiform lamellae. *Tellimya* was included by Thiele in the Erycinidae rather than the Montacutidae.

There is a general lack of agreement or concordance of interpretation among the major authors on the position of certain genera in families and subfamilies of the Erycinacea. At one time, the superfamily Cyamiacea, including such genera as *Cyamiomactra* and *Sportella*, was included in the Erycinacea. Members of the Cyamiacea possess two posterior mantle openings which act as inhalant and exhalant siphons, while the Erycinacea, on the other hand, have only a single posterior exhalant mantle opening, with the inhalant opening anteriorly. Accordingly, Thiele (1935) separated these distinct superfamilies as did Franc (1960) who used the names Cyamioidea for the Cyamiacea and Leptonoidea for the Erycinacea.

*Parabornia* possesses a single, posterior, exhalant, siphonal slit and an extensive anterior mantle opening which functions as the pedal-byssal as well as the inhalant orifice. Thus it is not cyamiacean but erycinacean in its affinities. In life, the probable direction of water flow through the mantle cavity of *Parabornia* is from the anterior mantle opening toward the short, posterior, exhalant mantle slit, a so-called primitive molluscan condition (Popham, 1939).

Thiele (1935) recognized two families in the Erycinacea, namely, the Ercinidae, with both inner and outer demibranchs in a ctenidium, and the Montacutidae, with only a single demibranch per ctenidium. *Parabornia* has two complete right and left ctenidia, with the outer demibranchs somewhat reduced; it therefore belongs within the Erycinidae of Thiele. Further, four subfamilies, the Erycininae, Leptoninae, Galeommatinae, and Chlamydoconchinae, comprise the Erycinidae according to Thiele, and, by the process of elimination, *Parabornia* may be excluded from the Chlamydoconchinae by its lack of a mantle which surrounds or encloses the shell. Since it was not possible to determine whether *Parabornia* is monoecious or dioecious or whether it is incubatory, its placement in one of the remaining subfamilies of Thiele's classification may be questioned.

The dioecious Leptoninae possess anterior and posterior differentiated papillae or tentacles and lack papillae ventrally; the shell has, in the left valve, both anterior and posterior teeth and, in the right valve, two anterior and posterior teeth. Clearly, *Parabornia* does not belong to the Leptoninae. The dioecious Galeommatinae have the valves gaping ventrally and the mantle covers part, if not all, of the shell externally. In addition, the galeommatids possess anterior and posterior differentiated papillae or "*Taster*," and the byssal gland is small. *Parabornia* differs from the Galeommatinae because it has a well-developed, extensive byssal gland, a narrow ventral gape that functions primarily for the passage of the byssus, and a mantle that is retractile into the shell cavity. The remaining group, the Erycininae, appears to be more heterogeneous, but still *Parabornia* differs by definition in that it possesses anterior differentiated papillae.[1] Of all the subfamilies of Thiele, *Parabornia* appears to belong to the Erycininae.

The Erycinidae as defined by Pelseneer (1911) included only *Kellia* and *Lasaea* and are, therefore, more restricted than the Erycininae of Thiele. Thiele did include both *Lasaea* and *Kellia* in his definition of the Erycininae but broadened the definition of the subfamily to include other genera. The Erycinidae, i.e., *Kellia* and *Lasaea* according to Pelseneer, have three pallial openings, namely, a posterior exhalant slit, an anterior inhalant opening, and a pedal-byssal opening. The genus *Parabornia*, with two openings in the mantle, is not closely allied to *Kellia* (= *Tellimya sensu* Thiele) or *Lasaea* (= *Kellya sensu* Thiele). From the other genera that Thiele included in the Erycininae, *Parabornia* also differs, particularly in the characters of the hinge. Of these genera, it may be most closely allied to *Bornia* in its development of the foot and byssal gland, its differentiated papillae, and its reduced outer demibranch. In addition, it has been shown that the muscular system of *Parabornia* is similar to that of *Bornia*, but the latter differs in its hinge configuration wherein the left valve has one large posterior tooth and two smaller anterior ones, while the right valve has one anterior tooth and two elongate posterior teeth.

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[1] This characteristic is apparently of little importance, because Thiele described *Ceratobornia* as possessing two anterior and one posterior differentiated papillae, but nevertheless he included it in the Erycininae.

The placement of *Parabornia* in the Erycininae of Thiele is a concession to our ignorance of the comparative morphology of the Erycinacea. The genus could be placed in Chavan's Montacutidae, but this family appears to be best characterized by its gill structure, which differs radically from that of *Parabornia*. The hinge of *Parabornia* comes close to the type described by Chavan for the group of *Tellimya* that Thiele had included in the Erycininae. Such a situation lends credence to the inclusion of the genus in the Erycininae.

Certainly, more inclusive, detailed, and comprehensive investigations similar to those of Popham (1940) and Deroux (1961) will define the generic and familial units of the Erycinacea and put the taxonomy of the group on a more sound foundation.

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## LITERATURE CITED

Burch, John Q., and Thomas Burch
1944. [No title.] Minutes Conchol. Club Southern California, no. 40, pp. 15-16.
Caullery, Maurice
1952. Parasitism and symbiosis. London, Sidgwick and Jackson Ltd., xii + 340

pp., 80 figs.

Chavan, André

1960. Remarques sur la charnière des Erycinacea et des Cyamiacea. Bull. Soc. Geol. France, ser. 7, vol. 1, pp. 712-718.

Cossmann, Maurice, and A. Peyrot

1912. Conchologie néogénique de l'Aquitaine. Bordeaux, Saugnac, vol. 1, pp. 429-718, figs. 81-136.

Dall, William H.

1899. Synopsis of the Recent and Tertiary Leptonacea of North America and the West Indies. Proc. U. S. Natl. Mus., vol. 21, pp. 873-893, pls. 87-88.

1900. Contributions to the Tertiary Fauna of Florida with especial reference to the Silex Beds of Tampa and the Pliocene Beds of the Caloosahatchie River including in many cases a complete revision of the generic groups treated of and their American Tertiary species. Trans. Wagner Free Inst. Sci. Philadelphia, vol. 3, pp. 949-1218, pls. 36-47.

Deroux, Gilbert

1961. Rapports taxonomiques d'un leptonacé non décrit "*Lepton subtrigonum*" Jeffreys (*nomen nudum*-1873). Cahiers de Biol. Marine, vol. 2, pp. 99-153, 18 figs., 1 pl.

Emerson, William K.

1944. [No title.] Minutes Conchol. Club Southern California, no. 41, p. 20.

Franc, André

1960. Classe des bivalves. *In* Grassé, Pierre-P., Traité de zoologie. Paris, vol. 5, pp. 1845-2133, figs. 1605-1802, pls. 9-10.

Hampson, George R.

1964. Redescription of a commensal pelecypod, *Rochefortia cuneata*, with notes on ecology. Nautilus, vol. 77, pp. 125-128, figs. 1a-f.

Holthuis, Lipke B.

1951. Note on *Caledoniella montrouzieri* Souverbie, a gastropod mollusc living commensally on stomatopod Crustacea. Basteria, vol. 15, pp. 69-71.

Kautsky, Fritz

1939. Die Erycinen des niederösterreichischen Miocaen. Ann. Naturhist. Mus. Wien, vol. 50, pp. 584-671, pls. 19-22.

MacGinitie, George E., and Nettie MacGinitie

1949. Natural history of marine animals. New York, McGraw-Hill, xii+473 pp., 282 figs.

Morton, John E.

1957. The habits of *Scintillona zelandica* (Odhner) 1924 (Lamellibranchia; Galeommatidae). Proc. Malacol. Soc. London, vol. 32, pp. 185-188, figs. 1-2.

Pelseneer, Paul

1909. Phylogénie des lamellibranches commensaux. Bull. Cl. Sci., Acad. Roy. Belgique, no. 12, pp. 1144-1150.

1911. Les lamellibranches de l'expedition du Siboga. Partie anatomique. *In* Siboga-Expeditie, 1899-1900. Leiden, Brill, Monographie 53a, 125 pp., 26 pls.

1925. Un lamellibranche commensal de lamellibranche et quelques autres lamellibranches commensaux. Trav. Sta. Zool. Wimereux, vol. 9, pp. 164-182, figs. 1-10.

1935. Essai d'ethologie zoologique d'après l'étude des mollusques. Publ. Fondation Agathon de Potter, Acad. Roy. Belgique, Sci., no. 1, 662 pp.

Popham, Mary L.

1939. On *Phlyctaenachlamys lysiosquillina* gen. and sp. nov., a lamellibranch commensal in the burrows of *Lysiosquilla maculata. In* Scientific reports, Great Barrier Reef Expedition 1928-29. London, British Museum (Natural History), vol. 6, pp. 61 84, 21 figs.

1940. The mantle cavity of some of the Erycinidae, Montacutidae and Galeommatidae with special reference to the ciliary mechanism. Jour. Marine Biol. Assoc. United Kingdom, vol. 24, pp. 549 587, 26 figs.

Smith, Allyn G., and MacKenzie Gordon

1948. The marine mollusks and brachiopods of Monterey Bay, California, and vicinity. Proc. California Acad. Sci., ser. 4, vol. 26, pp. 147-245, 4 figs., pls. 3-4.

Thiele, Johannes

1935. Handbuch der systematischen Weichtierkunde. Jena, Gustav Fischer, vol. 2, pp. 779-1022, 110 figs.

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# NOTE ON LIMA (ACESTA) ANGOLENSIS

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Fifteen specimens of *Lima (Acesta) angolensis* Adam and Knudsen were trawled by the U. S. Bureau of Commercial Fisheries vessel *Geronimo* on 9 September, 1963, while participating in the *Equalant II* program. All specimens were taken alive in a depth of 951 meters at *Geronimo* Station 249, 04°40′S and 11°00′E, about 55 miles west of Pointe Noire, Congo Republic (Brazzaville). Neither the bottom type nor any hydrographic data were recorded. The original description of *angolensis* (Adam and Knudsen, 1955) was based on the holotype, which was collected by the Belgian Oceanographic Expedition (1948-1949) at Station 88, 10°45′S, 13°07′E, about 40 miles west of Ponta do Môrro, Angola, in 400-500 meters. The *Geronimo* specimens constitute the second known occurrence of the species, increase the bathymetric range 450 meters, extend the geographic range about 360 miles northward, and add significant information on its biology.

Adam and Knudsen (1955) pointed out that *angolensis* is closely related to *Lima (Acesta) excavata* (Fabricius), an eastern north Atlantic species which ranges from Norway to the Azores in depths of 150-1450 fathoms (Thiele, 1918; Vokes, 1963a). In comparing *excavata* with *angolensis,* Adam and Knudsen noted the differences of the shape of the auricles, the size of the lunule, the strength of the ridges which define the lunule, and the development of the rudimentary lateral teeth. This latter trait was described:

"Le plateau cardinal de la valve droite présente à chaque extrémité un nodule; dans la valve gauche il y a aux endroits correspondants de chaque côté deux nodules allongés et parallèles. Ces nodules sont tous très peu apparents."

Dall (1902) documented the occurrence of lateral teeth in *Lima (Acesta) goliath* Sowerby and *Lima (Acesta) patagonica* Dall, and he mentioned that *excavata* lacked lateral teeth. A comparison of *excavata* from Hardanger Fjord, Norway, with *angolensis* shows that distal marginal irregularities, which could be considered obsolete lateral dental elements, occur in both species, rendering this character diagnostically unsuitable.

Other morphological characters, including conchological measurements, afford further specific parameters which may define the species. Table 1 gives some measurements of *angolensis* and *excavata.* The mean height/length ratio of *angolensis* is less than that of *excavata* but the overlap is considerable. More important are the ratios, breadth/height and breadth/length; both of them indicate that *excavata* has a greater lateral expansion. In these ratios, the amount of overlap is small. As pointed out by Vokes (1963b), the posterior auricle of *angolensis* is shorter than that of *excavata,* giving the outline of the shell a more broadly rounded posterior dorsal margin. Further, in *angolensis* the

| | Height | Length | Breadth | Height/length | Breadth/height | Breadth/length |
|---|---|---|---|---|---|---|
| angolensis | | | | | | |
| holotype | 153 | 122 | 49 | 1.30 | 0.32 | 0.40 |
| 1 | 164 | 127 | 59 | 1.30 | 0.40 | 0.50 |
| 2 | 162 | 123 | 62 | 1.31 | 0.40 | 0.50 |
| 3 | 159 | 120 | 66 | 1.32 | 0.41 | 0.60 |
| 4 | 159 | 119 | 50 | 1.33 | 0.31 | 0.42 |
| 5 | 156 | 137 | 58 | 1.13 | 0.40 | 0.42 |
| 6 | 154 | 117 | 59 | 1.31 | 0.40 | 0.50 |
| 7 | 152 | 116 | 59 | 1.31 | 0.40 | 0.50 |
| 8 | 148 | 113 | 57 | 1.30 | 0.40 | 0.50 |
| 9 | 142 | 111 | 57 | 1.30 | 0.40 | 0.51 |
| 10 | 139 | 114 | 51 | 1.21 | 0.40 | 0.48 |
| 11 | 133 | 103 | 49 | 1.30 | 0.40 | 0.50 |
| 12 | 130 | 104 | 44 | 1.30 | 0.33 | 0.42 |
| 13 | 123 | 103 | 48 | 1.20 | 0.40 | 0.50 |
| 14 | 105 | 81 | 31 | 1.30 | 0.30 | 0.40 |
| mean | | | | 1.28 | 0.38 | 0.47 |
| excavata | | | | | | |
| 1 | 135 | 101 | 62 | 1.33 | 0.50 | 0.61 |
| 2 | 122 | 92 | 60 | 1.32 | 0.50 | 0.70 |
| 3 | 121 | 89 | 48 | 1.40 | 0.40 | 0.53 |
| 4 | 115 | 86 | 46 | 1.33 | 0.40 | 0.53 |
| 5 | 106 | 81 | 42 | 1.30 | 0.40 | 0.51 |
| 6 | 105 | 82 | 52 | 1.30 | 0.50 | 0.63 |
| 7 | 104 | 80 | 46 | 1.30 | 0.44 | 0.60 |
| 8 | 103 | 76 | 39 | 1.40 | 0.40 | 0.51 |
| 9 | 91 | 65 | 35 | 1.40 | 0.40 | 0.53 |
| 10 | 80 | 71 | 39 | 1.30 | 0.43 | 0.54 |
| 11 | 88 | 64 | 35 | 1.40 | 0.40 | 0.54 |
| mean | | | | 1.34 | 0.43 | 0.56 |

Table I. Measurements in millimeters of *Lima (Acesta) angolensis* and *L. (A.) excavata.* Holotype data from original description; specimens of *angolensis* from *Geronimo* Station 249; those of *excavata* from Hardanger Fjord, Norway, in the collection of the U. S. National Museum.

anteroventral ridges which define the periphery of the lunule are stronger and more angular than the less definitive ridges in *excavata.* An internal view of the shell shows that the margin of the lunule of *angolensis* is more concave and lacks the strong proximal lunular notch of *excavata.* The radial sculpture is stronger and more widely spaced in *excavata,* perhaps a reflection of its heavier and thicker shell. The sculpture of *angolensis* is less well developed and finer, and the shell itself is thin and rather fragile.

Some epizoic commensal organisms were observed in association with *angolensis.* Two living specimens of a species of the prosobranch gastropod *Capulus,* here tentatively referred to as *C. ungaricus* (Linnaeus), were found attached to *angolensis* in the region of the margin of the lunule. The site of attachment on one specimen is about 30 millimeters in diameter and is impressed in the shell, forming a scar. Four of the limas exhibited these deformations of the shell, three on the right valves and one on the left. The left valve of the holotype of *angolensis* also possesses a similar disfiguration near the lunular margin. In one of the *Geronimo* specimens, an elongate hole was bored through the shell by *Capulus*. The snail lives with its apex directed away from the edge of the shell of its host, a condition similar to that exhibited by *Capulus ungaricus* on *Chlamys opercularis* (Linnaeus) in Europe (Sharman, 1956).

At least 6 of the specimens of *angolensis* have small, circular depressions which measure from one to three millimeters in diameter, distributed on the surface of the valves. These depressions are occupied by a species of the foraminiferan genus *Rosalina*. A complete penetration of the limid's shell may be effected in these depressions, and the mantle of the mollusk may secrete a conical deposit on the internal surface of the valve in a reaction against the irritation caused by the *Rosalina*. Other foraminiferan species of the genera *Cibicides* and *Placopsilina* may be attached to the shell externally.

The soft parts of all the specimens were preserved. None of them possessed a byssus; however, these limas may possibly attach byssally in the immature stage. The posterior pedal-byssal retractor muscle is small and inserts in the muscular portion of a special axial branchial apparatus which irregularly attaches to the shell posteroventral to the strong adductor muscle.

*Acknowledgments*. The specimens of *angolensis* were transmitted to the U. S. National Museum by Dr. J. Lockwood Chamberlin of the Bureau of Commercial Fisheries Biological Laboratory, Washington, D. C. Dr. Ruth Todd of the U. S. Geological Survey, Washington, D. C., identified the genera of Foraminifera.

## LITERATURE CITED

Adam, W., and J. Knudsen. 1955. Note sur quelques espèces de mollusques marins nouveaux ou peu connus de l'Afrique occidentale. Inst. roy. sci. nat. Belgique, Bull., *31* (61): 1-25, 2 pls.

Dall, W. H. 1955. Notes on the giant *Limas*. Nautilus, *16:* 15-17.

Sharman, M. 1956. Note on *Capulus ungaricus* (L.). J. Mar. Biol. Assoc. U. K., *35:* 445-450.

Thiele, J. 1918 [-1920]. Familia Limidae. Conchylien-Cabinet (N.F.), *7* (2), 66 pp., 10 pls.

Vokes, H. E. 1963a. Studies on Tertiary and Recent giant Limidae. Tulane Stud. Geol., *1* (2): 73-92, 2 pls.

Vokes, H. E. 1963b. Additions to a catalogue of the described Recent and Tertiary species of *Acesta* and *Plicacesta*. Tulane Stud. Geol., *2* (1): 18-20.

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# Occasional Papers On Mollusks

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## Catalogue of the Family Pandoridae (Mollusca: Bivalvia)

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The following catalogue was initiated during the preparation of a taxonomic revision of the family Pandoridae.[1] At the time of the completion of that manuscript, the catalogue was incomplete but of such magnitude that it was deemed worthwhile to carry it to completion. A work of this kind is primarily bibliographic and proceeds in a disconcertingly haphazard manner. The basic references, Sherborn's Index Animalium, the Zoological Record, and, in this case, the previous monographic work of Lamy, do not supply all the necessary information, nor do they incorporate all the specific taxa attributed to the family. It is by painstaking reference to original and subsequent literature and chance collation that a catalogue of this sort is compiled.

The presentation intends to include: 1) the generic, subgeneric, specific or subspecific name as originally introduced, 2) the original literature and date citation, 3) the type locality, including the geologic age in case of fossils, and 4) the whereabouts of the type specimens. Cases of taxa erroneously referred to *Pandora*, either originally or subsequently, are noted as not belonging to the family Pandoridae. Their correct systematic placement is indicated if known. If the type specimens could not be found, they are listed as lost; footnotes cite the authority for some of these statements. The actual existence of every type specimen has not been corroborated if the original statement of individual authors or the subsequent remarks of Lamy (1934), or Sherborn (1940), present the necessary documentation.

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[1] Boss and Merrill, 1964.

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## ABBREVIATIONS

ANSP — Academy of Natural Sciences of Philadelphia
BMNH — British Museum (Natural History)
CAS — California Academy of Science
MCZ — Museum of Comparative Zoology
MNHNP — Muséum national d'Histoire naturelle, Paris
USFC — United States Fish Commission
USGS — United States Geological Survey
USNM — United States National Museum

## Generic and Subgeneric Taxa

**Andora** 'Bruguière' Morse 1919. Proc. Boston Soc. Nat. Hist., **35**(5): 160, error for *Pandora* Bruguière 1797.

**Calopodium** Röding 1798, Museum Boltenianum, 1st Ed., p. 166 (type species, by monotypy, *Calopodium albidum* Röding, 1798 [ = *Tellina inaequivalvis* (Linnaeus, 1758)]).

**Cleidiophora** 'Carpenter' Conrad 1868. Amer. Jour. Conch., **3**(4): 269, error for *Clidiophora* Carpenter 1864.

**Clidiophora** Carpenter 1864. Proc. Zool. Soc. London, pt. 3, p. 596 (type species, by original designation, *Clidiophora claviculata* Carpenter 1855 [=*Pandora arcuata* Sowerby 1830]).

**Clidiphora** 'Carpenter' Johnson 1934. Proc. Boston Soc. Nat. Hist., **40**(1): 31, error for *Clidiophora* Carpenter 1864.

**Coelodon** Carpenter 1864. Proc. Zool. Soc. London, pt.3 , p. 599 (type species, by original designation, *Coelodon ceylanicus* (Sowerby 1835)), *non* Audinet-Serville 1832 (Coleoptera), *nec* Lund 1838 (Mammalia).

**Foveadens** Dall 1915. Proc. U.S. Nat. Mus., **49:** 451 (type species, by original designation [*Pandora*] *Foveadens panamensis* Dall 1915).

**Frenamya** Iredale 1930. Rec. Australian Mus., **17:** 387 (type species, by monotypy, *Coelodon patulus* Tate 1889).

**Heteroclidus** Dall 1903. Trans. Wagner Free Inst. Sci., **3**(6): 1518 (type species, by original designation, [*Pandora*] *Clidiophora punctata* Conrad 1837).

**Kenerlia** 'Carpenter' Paetal 1875. Fam. Gatt. Moll., p. 103, error for *Kennerlia* Carpenter 1864.

**Kenerlyia** 'Carpenter' Nomura and Hatai 1940. Saito Ho-on Kai Mus., Res. Bull., **19:** 87, error for *Kennerlia* Carpenter 1864.

**Kennerleya** 'Carpenter' Fischer 1887. Manuel de Conchy., p. 1158, emend. for *Kennerlia* Carpenter 1864.

**Kennerleyia** 'Carpenter' Dall 1903. Trans. Wagner Free Inst. Sci., **3**(6): 1517, emend. for *Kennerlia* Carpenter 1864.

**Kennerlia** Carpenter 1864 (Aug.). Brit. Assn. Adv. Sci., Rept. for 1863, pp. 602 and 638; 1864 (Nov.). Proc. Zool. Soc. London, pt. 3, p. 602 (type species, by subsequent designation, Stoliczka 1871, p. 61, *Pandora* (*Kennerlia*) *bicarinata* Carpenter1864 [=*Pandora* (*Kennerlia*) *bilirata* Conrad 1855]).

**Kennerlyia** 'Carpenter' Dall 1915. Proc. U.S. Nat. Mus., **49:** 448, error for *Kennerlia* Carpenter 1864.

**Kenverlia** 'Carpenter' Nomura and Hatai 1940. Saito Ho-on Kai Mus., Res. Bull., **19:** 88, error for *Kennerlia* Carpenter 1864.

**Panderella** 'Conrad' Palmer 1958. Memoir 76, Geol. Soc. Amer., p. 76, error for *Pandorella* Conrad 1863.

**Pandora** Bruguière 1797, Encyclopédie Méthodique, Vers Testacés, pl. 250, figs. 1 a–c; Lamarck 1799, Mem. Soc. Hist. Nat. Paris, an. vii, p. 88 (type species by subsequent monotypy, Lamarck 1799, *Tellina inaequivalvis* (Linnaeus 1758)), *non* Mühlfeld 1811 (Mollusca), *nec* Eschscholtz 1829 (Ctenophora), *nec* Haliday 1833 (Diptera), *nec* Chevrolat 1834 (Coleoptera), *nec* Westwood 1848 (Lepidoptera), *nec* Kock 1850 (Arachnida), *nec* Sars 1895 (Crustacea).

**Pandorella** Conrad 1863. Proc. Acad. Nat. Sci. Philadelphia, for 1862, p. 572 (type species, by monotypy, *Pandora arenosa* Conrad 1834), *non* Laseron 1951 (Mollusca).

**Pandorina** Scacchi 1836. Catalogus conchyliorum regni neapolitani, p. 6, *non* Scacchi 1833 (Mollusca), *nec* Bory de St. Vincent 1827 (Protozoa).

**Trutina** Brown 1827. Illustrations of the Conchology of Great Britain and Ireland, 1st. Ed., pl. 13, fig. 5 (type species, by monotypy, *Trutina solenoidea* Brown 1827 [=*Tellina inaequivalvis* (Linnaeus 1758)]).

## Specific and Subspecific Taxa

**acutedentata** Carpenter 1864, **Clidiophora.** Proc. Zool. Soc. London, pt. 3, p. 598, substitute name for *cornuta* C. B. Adams 1852.

**acutirostrata** Clark 1918, **Pandora (Pandora).** Univ. Cal. Publ., Bull. Dept. Geol., **11**(2): 138, pl. 11, figs. 7, 9, 13 (University of California Locality 1131, ½ mile SW of town of Walnut Creek in creek bed about 100 yards to E of Oakland and Antioch bridge; elevation 150 feet; Contra Costa Co., 122°4′8″ W, 37°53′7″ N; holotype, Invert. Coll'n, Museum of Paleontology, University of California, No. 11111).

**aequivalvis** Philippi 1836, **Pandora.** Enum. Moll. Siciliae, **1:** 18, pl. 1. fig. 11 (fossilis in calcareo Panormitano [Sicily]) [not a *Pandora*].

**aequivatris** 'Philippi' Philippi 1844, **Pandora.** Enum. Moll. Siciliae, **2:** 16, error for *aequivalvis* Philippi 1836.

**albidum** Röding 1798, **Calopodium.** Museum Boltenianum, 1st Ed., pt. 2, p. 166; 1819, 2nd Ed., pt. 2, p. 116 (substitute name for *Tellina inaequivalvis* (Linnaeus 1758)).

**arctica** Dall 1903, **Pandora (Kennerleyia).** Trans. Wagner Free Inst. Sci., **3**(6): 1520, pl. 57, fig. 26 (Saco, Maine [Pleistocene]: holotype, USNM 109290).

**arcuata** Sowerby 1835, **Pandora.** Proc. Zool. Soc. London, p. 93 (Hab. apud Sanctam Elenam; syntypes, BMNH, Reg. No. 1964467).[1]

**arenata** 'Sowerby' H. and A. Adams 1865, **Pandora.** Gen. Rec. Moll., **2:** 371, *nomen nudum.*

**arenosa** Conrad 1834, **Pandora.** Jour. Acad. Nat. Sci. Philadelphia, **7**(1); 130–1 (Yorktown, Virginia [Miocene]; syntypes, ANSP 30584).

**aversus** Hedley 1913, **Coelodon.** Proc. Linn. Soc. New South Wales, **37**(2): 266 (Mast Head Island in 17–20 fathoms [Queensland, Australia]; holotype, Reg. no. C 19389, Australian Museum, Sydney) [see Hedley 1906, ibid, **31** (3): 473–4, pl. 37, fig. 16, *Coelon elongatus* 'Carpenter'].

**bicarinata** Carpenter 1864, **Kennerlia.** Proc. Zool. Soc. London, pt. 3, p. 603 (Catalina Island, California; holotype, USNM 592440).

**bilirata** Conrad 1855, **Pandora.** Proc. Acad. Nat. Sci. Philadelphia, 1st ser., **7:** 267 (California [Miocene]; types, lost [See Palmer, 1958, p. 77]).

**brasiliensis** 'Gould' Paetal 1890, **Pandora.** Catalog der Conchylien-Sammlung **3:** 28, error for *braziliensis* 'Gould MS' Sowerby [in] Reeve 1874.

**braziliensis** 'Gould MS' Sowerby [in] Reeve 1874, **Pandora.** Conch. Icon., **19, Pandora,** pl. 2, fig. 15 (Brazil; holotype, BMNH, Reg. No. 1964464).

**brevifrons** Sowerby 1835, **Pandora.** Proc. Zool. Soc. London, p. 93 (Hab. apud Panamam; types lost).

**brevis** Sowerby 1829, **Pandora.** Catal. Coll. S. Stutchbury, 1, Appx., p. 3 [not a *Pandora;* is the type species of *Myadora* Gray 1840].

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[1] The illustrations of *Pandora arcuata, P. brevifrons, P. ceylanica, P. discors* and *P. radiata* were first published in 1854 in Hanley's 'The Conchological Miscellany.'

**brevis** Verrill and Bush 1898, **Kennerlia.** Proc. U.S. Nat. Mus., **20:** 821, pl. 88, figs. 7a–b (USFC *Albatross* I, station 2248, S of Nantucket, Massachusetts, in 67 fathoms; holotype, USNM 40232).

**brunnichi** 'Beck MS' Lamy 1934, **Pandora.** Jour. de Conchy., **78**(2): 105, *nomen nudum.*

**bushiana** Dall 1886, **Pandora (Kennerlia).** Bull. Mus. Comp. Zool., **12**(6): 312 (Tampa, Florida, in 6 fathoms; holotype, USNM 61029).

**carinatum** Prashad 1932, **Calopodium (Kennerlia).** The Lamellibranchia of the Siboga Expedition. Systematic Part (Monograph 53c). II Pelecypoda, p. 323, pl. 7, figs. 15–18 (*Siboga* station 159, 0°59.1′ S; 129°48.8′ E, in 411 meters [N of Poelau Kofiau, Halmaheira Sea]; holotype, Zoölogisch Museum, Amsterdam).

**carolinensis** Bush 1855, **Pandora.** Trans. Conn. Acad., **6**(2): 474 (USFC *Albatross I* station 2113, off Cape Hatteras, North Carolina, in 15 fathoms; holotype, USNM 35701).

**ceylanica** Sowerby 1835, **Pandora.** Proc. Zool. Soc. London, p. 94 (in Mari Ceylanico, et apud Insulam Muerte, Colombiae Occidentalis [Ceylon]; holotype, BMNH, Reg. No. 196271).

**ceylonica** 'Sowerby' Hanley 1842, **Pandora.** Catalogue Recent Bivalve shells, p. 50, error for *ceylanica* Sowerby 1835.

**cistula** Gould 1850, **Pandora.** Proc. Boston. Soc. Nat. Hist., **3:** 217 (East Patagonia; holotype, USNM 5887).

**clavata** McCoy 1844, **Pandora.** [in] Griffith, Synopsis Carboniferous limestone fossils Ireland, p. 51, pl. 11, fig. 2 (no locality given) [not a *Pandora*].

**claviculata** Carpenter 1855, **Pandora.** Proc. Zool. Soc. London, pt. 23, p. 228 (Mazatlan, Mexico; syntypes, BMNH, Reg. No. 196252).

**clavisulcata** 'Carpenter' Paetal 1883, **Pandora.** Catalog der Conchylien-Sammlung, p. 199, error for *claviculata* Carpenter 1855.

**conradi** Mansfield 1929, **Pandora (Clidiophora).** Proc. U.S. Nat. Mus., **74** (14): 8, pl. 5, figs. 4, 5 (USGS station 1/221, near the bottom of a small ravine entering Blackwater River and about a quarter of a mile from it and one and one-half miles W of Walters, Virginia [Miocene]; holotype, USNM 352441).

**convexa** Dall 1915, **Pandora (Kennerlyia).** Proc. U.S. Nat. Mus., **49:** 449 (Ballenas Lagoon, Lower California, in 48 fathoms; holotype, USNM 171068).

**copiosa** Sorgenfrei 1958, **Pandora.** Danmarks Geologiske Undersögelse, II Raekke, Nr. 79, **1:** 138; **2:** pl. 24, figs. a–e [not a–d, as in text] (Toftlund, 105–110 m. depth [Miocene]; holotype, Geological Survey of Denmark, file no. 150.9.b).

**cornuta** C. B. Adams 1852, **Pandora.** Ann. Lyc. Nat. Hist., New York, **5:** 519 (Panama; holotype, MCZ 186309).

**costata** 'Lamarck' Pallary 1920, **Pandora.** Exploration scientifique du Maroc. Fasc. II. Malacologie (1912), p. 98, error for *rostrata* Lamarck 1818.

**crassa** Conrad 1868, **Pandora (Cleidiophora** [*sic*]**).** Amer. Jour. Conch., **3**(4): 269, error for *crassidens* Conrad 1838.

**crassidens** Conrad 1838, **Pandora.** Fossils Medial Tertiary United States, p. 2, pl. 1, fig. 2 (James River, near Smithfield, Virginia [Miocene]; types lost [see Moore, 1962, p. 50]).

**cristata** Carpenter 1864, **Clidiophora.** Proc. Zool. Soc. London, pt. 3, p. 597 (Gulf of California; holotype, BMNH, Reg. No. 1963441).

**cumingi** 'Hanley' Lamy 1934, **Pandora (Coelodon).** Jour. de Conchy., **78** (2): 116, error for *cumingii* Hanley 1861.

**cumingii** Hanley 1861, **Pandora.** Proc. Zool. Soc. London, pt. 2, p. 272 (Samar et Negros, Insulas Philippinas; syntypes, BMNH, Reg. No. 1964466).

**dalli** Gardner 1943, **Pandora (Kennerlia).** U.S. Geological Survey, Prof. Paper 199-A, p. 45, pl. 10, figs. 21, 24, 26 (one-quarter of a mile below Jones Point, Essex County, Virginia [Miocene]; holotype, USNM 325503).

**defrancei** 'Deshayes' Deshayes 1860, **Pandora.** Desc. Anim. s. Vert. du Bassin de Paris, **1:** 243, error for *defrancii* Deshayes 1824.

**defrancii** Deshayes 1824, **Pandora.** Desc. Coq. foss. Paris, **1:** 61, pl. 9, figs. 15–17 (Grignon [Eocene]; holotype, l'École des Mines, vitrine 32).

**degrangei** Cossmann and Peyrot 1909, **Pandora.** Conchologie néogénique de l'Aquitaine, Livraison 1, p. 40, pl. 1, figs. 15–18 (Sallespisse, environs d'Orthez, Basses pyrénées (Helvetien supérieur [Miocene]); holotype, Degrange-Touzin collection [*teste* Cossmann and Peyrot], Faculté des Sciences, Bordeaux [*teste* Mongin, *in litt.*]).

**delicatulus** A. Adams [in] Carpenter 1864, **Coelodon.** Proc. Zool. Soc. London, pt. 3, p. 600 [Japan[1]; holotype, BMNH, Reg. No. 196274).

**depressa** Sowerby 1830, **Pandora.** [in] Broderip and Sowerby, Species Conchyliorum, **1**(1): *Pandora*, p. 3, figs. 11, 12 (hab. in littoribus Insularum Maris Pacifici; types lost [see Carpenter 1864, p. 598]).

**diffissa** Mabille et de Rochebrune 1889, **Pandora.** Miss. scient. Cap Horn, Moll., p. 103 (New Year Sound [Cape Horn, 54°45′ S; 64°07′ W]; holotype, MNHNP; [*teste* Lamy 1934]).

**dilatata** Deshayes 1860, **Pandora.** Desc. Anim. s. Vert. du Bassin de Paris, **1:** 243, pl. 17, figs. 6–9 (Parnes, Mouchy [Eocene]; holotype, l'École des Mines, vitrine 32).

**discors** Sowerby 1835, **Pandora.** Proc. Zool. Soc. London, p. 93 (no locality given; holotype, BMNH, 1964465).

**dissimilis** Sowerby 1894, **Pandora.** Jour. of Conch., **7:** 374 (Sea Point, Cape Town, South Africa; holotype, BMNH, Reg. No. 1899.4.14.2845).[2]

**dodona** Dall 1903, **Pandora (Kennerleyia).** Trans. Wagner Free Inst. Sci., **3**(6): 1518, pl. 57, fig. 25 (uppermost Oligocene sands of Oak Grove, Santa Rosa County, Florida [Miocene]; holotype, USNM 135848a).

**edwardsi** Jousseaume 1891, **Pandora.** Le Naturaliste, 13 ann., 2 ser., no. 107, p. 201 (Aden; type lost [see Lamy 1934, p. 118]).

**elongata** Risso 1826, **Pandora.** Hist. Nat. Europe Meridionale, **4:** 373 (La Trinité, Alpes Maritimes [? age]; holotype, Muséum d'Histoire naturelle, Nice [*teste* Risso]).

**elongatus** Carpenter 1864, **Coelodon.** Proc. Zool. Soc. London, pt. 3, p. 600 (China and Borneo; syntypes, BMNH, Reg. No. 196272).

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[1] This locality was given subsequently by Sowerby [in] Reeve, 1874, Conch. Icon., **19, Pandora,** pl. 3, fig. 17.

[2] Barnard (1964, p. 572) lists a cotype in the South African Museum, Reg. No. 5622. The specimen may be a paratype.

**eutaenia** Dall 1915, **Pandora (Kennerlyia) glacialis.** Proc. U.S. Nat. Mus., **49:**449 (Sitka Harbor, Alaska, in 15 fathoms; syntypes, USNM 171062).

**filosa** Carpenter 1864, **Kennerlia.** Proc. Zool. Soc. London, pt. 3, p. 602 (Puget Sound, Washington; syntypes, USNM 4542).

**flexuosa** Sowerby 1822, **Pandora.** Genera of Recent and Fossil Shells, **2,** *Pandora,* figs. 4, 5 (East Indies [Red Sea[1]]; types lost).

**floridana** Dall 1886, **Pandora (Clidiophora).** Bull. Mus. Comp. Zool., **12** (6); 312, *nomen nudum.*

**forresterensis** Willett 1918, **Pandora (Kennerlyia).** Nautilus, **31**(4): 134 (Forrester Island, Alaska, in 50 fathoms; holotype, ANSP 118200).

**gabbi** Dall 1903, **Pandora (Heteroclidus) punctata.** Trans. Wagner Free Inst. Sci., **3**(6): 1521 (Miocene of California near San Buenaventura; holotype, USNM [lost]).

**glacialis** Leach 1819, **Pandora.** Jour. de Physique, **88:** 465 (Baffin's Bay. . . Spitzbergen [restricted to Baffin's Bay, Boss and Merrill (1965, p. 209)]; syntypes, BMNH, Reg. No. 196273).

**gouldiana** Dall 1886, **Pandora(Clidiophora).** Bull. Mus. Comp. Zool., **12** (6): 312 (Woods Hole, Massachusetts; holotype, USNM 95490).

**grandis** Dall 1877, **Pandora (Kennerlia).** Proc. Calif. Acad. Sci., **7:** 11 (Unalashka [*sic*], in 100 fathoms; holotype, USNM 171069).

**granulata** Dall 1915, **Pandora (Kennerlyia).** Proc. U.S. Nat. Mus., **49:** 449 (La Paz, Lower California; holotype, USNM 211348).

**granum** 'Benoist MS' Cossmann 1896, **Pandora.** Sur quelques formes nouvelles ou peu connues des faluns du Bordelais. Association Française pour l'avancement des Sciences, Comte Rendu de la 24me session, Bordeaux 1895, pt. 2, p. 509, pl. 4, figs. 1, 2 (du moulin de l'Eglise, Saucats [St. Médard], Burdigalien [Miocene]; cotypes, Cossmann collection, Laboratoire Géologie Sorbonne, meuble XVI, tirior 1, no. 7678).

**grateloupi** 'Nyst' Bronn 1848, **Pandora.** Index Paleo., **2:** 904, error for *grateloupii* Nyst 1843.

**grateloupii** Nyst 1843, **Pandora.** Desc. Coq. Belgique, p. 74, *nomen nudum.*

**gretschischkini** Slodkewitsch 1938, **Pandora.** Paleontology of USSR, Vol. 10, pt. 3, fasc. 19, Tertiary Pelecypoda from the Far East, Pt. 1, p. 270 [in Russian], Pt. 2, p. 125 [in English], pl. 59, figs. 2a–b (sea coast between sea cliffs and mouth of Etalonnaya River, west coast of Kamchatka, Upper Pliocene; holotype, Geological Museum, F. N. Chernyshev, No. 101/ c 753).

**heberti** de Raincourt 1870, **Pandora.** Bull. Soc. Géol. France, 2nd Ser., **27:** 629, pl. 14, fig. 7 (Le Vivray [Eocene]; holotype, de Raincourt collection, l'École des Mines, vitrine 32).

**higginsoni** 'Phillippi MS' Paetal 1873, **Pandora.** Catalog der Conchylien-Sammlung, p. 129 (Boston; *nomen nudum*).

**hukusimana** Otuka 1943, **Pandora (Heteroclidus).** Jour. Geol. Soc. Japan, **50**(592): 25, pl. 2, fig. 8 (Iisaka and Manseioozi, Hukusima, Pref. [Miocene]; holotype destroyed in World War II [*teste* Habe]).

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[1] This locality was subsequently designated by Sowerby [in] Broderip and Sowerby 1830, Species Conchyliorum, **1**(1): *Pandora,* p. 3.

**inaequalis** 'Linnaeus' Carpenter 1864, **Tellina** [**Pandora**]. Proc. Zool. Soc. London, pt. 3, p. 601, error for *inaequivalvis* Linnaeus 1758.

**inaequivalvis** Linnaeus 1758, **Solen.** Systema naturae, 10th Ed., p. 673, no. 32; 1767, Systema naturae, 12th Ed., p. 1118, *Tellina,* no. 56 (in M. Mediterraneo; holotype, Linnean Collection, Linnean Society, London).

**inconspicua** Gabb 1873, **Pandora**. Trans. Amer. Philos. Soc., **15:** 248 (Tertiary of Santo Domingo; lectotype and paralectotypes, selected by Pilsbry, 1922, Proc. Acad. Nat. Sci. Philadelphia, **73:** 414, ANSP 2676).

**indica** Chenu 1862, **Pandora.** Man. Conch., **2:** 51, fig. 214 (no locality given; holotype, Muséum d'Histoire Naturelle, Geneva).

**inflata** Boss and Merrill 1965, **Pandora** (**Pandorella**)**.** Johnsonia, **4**(44): 205, pl. 124, figs. 1–4, pl. 125, figs. 1–2, new name for *brevis* Verrill and Bush 1898, *non* Sowerby 1829.

**inornata** Verrill and Bush 1898, **Clidiophora.** Proc. U.S. Nat. Mus., **20:** 819, pl. 95, figs. 5, 6 (*Speedwell* station 327, off Cape Cod, south end of Stellwagen Bank, in 17 fathoms; syntypes, USNM 49760).

**intermedia** Jeffreys 1881, **Pandora inaequivalvis.** Proc. Zool. Soc. London, pt. 4, p. 929, *nomen nudum.*

**japanensis** Nomura and Hatai 1940, **Pandora** (**Kenerlyia**)**.** Saito Ho-on Kai Mus., Res. Bull., **19:** 86, pl. 4, figs. 13 a–d and 14 a–b (Kyuroku-sima, Aomori Pref., Honshu; holotype, Saito Ho-on Kai Museum, Sendai, Japan, Reg. no. 14734).

**lata** Dall 1903, **Pandora** (**Kennerleyia**)**.** Trans. Wagner Free Inst. Sci., **3** (6): 1520, pl. 57, fig. 18 (Miocene of Maryland; holotype, USNM 11875).

**lemensis** Coen 1937, **Pandora.** R[ept.] Comitato Talassografico Italiano, Mem. 240, p. 166 (Canal di Leme, Istria; holotype, Coen Collection [*teste* Coen]).

**majorina** Gardner 1943, **Pandora** (**Clidiophora**) **crassidens.** U.S. Geological Survey, Prof: Pap. 199-A, p. 47, pl. 10, figs. 25, 28 (Halifax on Quankey Creek, Halifax County, North Carolina [Miocene]: holotype, USNM 325501).

**margaritacea** Lamarck 1801, **Pandora.** Syst Anim. s. vert., p. 137, substitute name for *Tellina inaequivalvis* (Linnaeus 1758).

**maxima** Megerle von Muhlfeld 1811, **Pandora.** Gesellschaft Nat. Freunde, Magazin, Berlin, **5**(1): 59 [not a *Pandora*].

**nasuta** Sowerby 1830, **Pandora.** [in] Broderip and Sowerby, Species Conchyliorum, **1**(1): *Pandora,* p. 3, figs. 18, 19 (locality unknown; types lost).

**naviculoides** Gardner 1943, **Pandora** (**Kennerlia**)**.** U.S. Geological Survey, Prof. Pap. 199-A, p. 46, pl. 10, figs. 22, 23 (Neills Eddy Landing, Columbus County, North Carolina [Pliocene]; holotype, USNM 325504).

**nipponica** Habe 1952, **Pandora** (**Kennerlia**)**.** [in] Kuroda, Ill. Cat. Japanese Shells, no. 18, p. 125, pl. 18, fig. 6 (Tosa Bay, Shikoku, about 120 fathoms depth; holotype, National Science Museum, Tokyo, Reg. No. 13313).

**oblonga** Sowerby 1830, **Pandora.** [in] Broderip and Sowerby, Species Conchyliorum, **1**(1): *Pandora,* p. 2, fig. 10 (from Gamberoon; types lost).[1]

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[1] As remarked and discussed by Lamy (1934, p. 107), this species has been the center of some controversy. In the present literature, it appears that the species of *Pandora* which is found on the coast of West Africa has been called *oblonga* Sowerby.

**obtusa** 'Leach MS' Lamarck 1818, **Pandora.** Anim. s. Vert., **5:** 499 (Habite . . . l'Ocean britannique; holotype, Muséum d'Histoire Naturelle, Geneva).

**obovata** 'Conrad' Sherborn 1929, **Pandora.** Index Animalium, p. 4479, *lapsus* for *Cytherea obovata* Conrad.

**otukai** Habe 1952, **Pandora (Kennerlia).** Gen. Jap. Shells, **3:** 259, figs. 689, 690 (name and figures only); [in] Kuroda, Ill. Cat. Jap. Shells, no. 18, p. 124, pl. 18, figs. 11, 12 (Sagami Bay, Honshu, about 50 fathoms in depth; holotype, National Science Museum, Tokyo, Reg. No. 13314).

**panamensis** Dall 1915, **Pandora (Foveadens).** Proc. U.S. Nat. Mus., **49:** 451 (Old Panama [Pacific Ocean]; holotype, USNM 252276).

**patagonica** Dall 1915, **Pandora (Kennerlyia).** Proc. U.S. Nat. Mus., **49:** 450 (west coast of Patagonia [*sic*], in 61 fathoms; holotype, USNM 96937).

**patulus** Tate 1889, **Coelodon.** Trans. and Proc. and Rept. Roy. Soc. South Australia (1887–1888), **11:** 60, pl. 11, fig. 1 (Wool Bay, South Australia, in 10 fathoms; holotype, South Australian Museum, Adelaide, Reg. No. D. 13207).

**perangusta** Preston 1910, **Pandora.** Rec. Ind. Mus., **5**(11): 120, fig. 5 (off the Devi River, Orissa Coast, Bay of Bengal, 17–20 fathoms; holotype, Indian Museum, Calcutta, Reg. No. M. 4686/1).

**pinna** Montagu 1803, **Solen.** Testacea Britannica, pt. 1, p. 566, pl. 15, fig. 3 (Torcorss, England; types not in BMNH, possibly in Exeter Museum).

**pinnoides** 'Montagu' Locard 1899, **Pandora.** Coq. mar. côtes de France, p. 261, emendation for *pinna* Montagu 1803.

**primaeva** Deshayes 1860, **Pandora.** Desc. Anim. s. Vert. du Bassin de Paris, **1:** 244, pl. 11 *bis,* figs. 16–18 (Aizy; [Eocene]; syntypes, l'École des Mines, vitrine 32),

**prodromus** Gardner and Aldrich 1919, **Pandora (Clidiophora).** Proc. Acad. Nat. Sci. Philadelphia, **71:** 44, pl. 4, figs. 9, 11, 12, 14 (Yorktown, York County Virginia, Yorktown Formation [Miocene]; holotype, USNM 325499).

**pseudobilirata** Nomura and Hatai 1940, **Pandora (Kenerlyia.** Saito Ho-on Kai Mus., Res. Bull., **19:** 87, pl. 19 [4], figs. 15 a and 15 b (Kyuroku-sima, Aomori Pref., Honshu; holotype, Saito Ho-on Kai Museum, Sendai, Japan, Reg. No. 14733).

**pulchella** Yokoyama 1926, **Pandora.** Jour. Fac. Sci. Imperial Univ., Tokyo, Sec. 2, **1**(9): 387, pl, 45, fig. 4 (Anden, Akita Pref., Honshu [Pliocene]: holotype destroyed in World War II [*teste* Habe]).

**punctata** Conrad 1837, **Pandora.** Jour. Acad. Nat. Sci. Philadelphia, **7**(2): 228, pl. 17, fig. 1 (Santa Barbara, California; types lost. Not in Moore (1962).

**radians** Dall 1915, **Pandora (Coelodon).** Proc. U.S. Nat. Mus., **49:** 450 (near Ballenas Lagoon, Lower California, in 5½ fathoms; holotype, USNM 171053).

**radiata** Sowerby 1835, **Pandora.** Proc. Zool. Soc. London, p. 94 (apud Insulam, Muerte, Colombiae Occidentalis [Isla del Muerto, Gulf of Guayaquil, Ecuador]; holotype, BMNH, Reg. No. 1964469).

**rhypis** Pilsbry and Lowe 1932, **Pandora (Kennerlia).** Proc. Acad. Nat. Sci. Philadelphia, **84:** 105, pl. 16, figs. 8–11 (La Union, Gulf of Fonseca, San [*sic*] Salvador; holotype, ANSP 155503).

**rostrata** Lamarck 1818, **Pandora.** Anim. s. Vert., **5:** 498 (habite la Méditerranée et dans la Manche, sur nos côtes; holotype, Museum d'Histoire Naturelle, Geneva).

**scapha** Gabb 1866, **Pandora.** Tertiary Invertebrate Fossils, Palaeo. Calif., v. 2, sect. 1, pt. 1, p. 18 (from the Miocene, west of Martinez, California; holotype, ANSP 4539).

**scapho** 'Gabb' Merriam and Clark [in] Lawson 1914, **Pandora.** San Francisco Folio, U.S. Geol. Survey Folio 193, p. 11, error for *scapha* Gabb, 1866.

**sicula** 'Sowerby MS' Lamy 1934, **Pandora (Pandora) inaequivalvis.** Jour. de Conchy., **78**(2): 103 (Palermo, Sicily; syntypes, MNHNP [*teste* Lamy 1934]).

**similis** Sowerby 1897, **Pandora.** Appendix to Marine Shells South Africa, p. 29 (Durban; holotype, BMNH, Reg. No. 1964470).[1]

**solenoidea** Brown 1827, **Trutina.** Ill. Conch. Great Britain and Ireland, pl. 13, fig. 5, substitute name for *Solen pinna* Montagu 1803.

**squamula** 'Payraudea MS' Lamy 1934, **Pandora.** Jour. de Conchy., **78**(2): 105 (Ajaccio, Corsica; *nomen nudum*).

**striata** Quoy and Gaimard 1835, **Pandora** [in] D'Urville, Voyage l'Astrolabe, Zoologie, **3:** 537, pl. 83, fig. 10 (New Zealand; holotype, MNHNP), [is a species of *Myadora* Gray 1840].

**tabacea** 'Meuschen' Carpenter 1864, **Clidiophora** [**Anomia**]. Proc. Zool. Soc. London, pt. 3, p. 597, *nomen nudum.*

**tenuis** Jeffreys 1865, **Pandora inaequivalvis**. Brit. Conch., **3:** 25 (between 85 and 100 f[athoms], off Unst. Shetland; types lost).

**trilineata** Say 1822, **Pandora.** Jour. Acad. Nat. Sci. Philadelphia, 1st Ser., **2:** 261 (Great Egg Harbor, New Jersey; types lost [not in ANSP]).

**truncata** 'Turton' Paetal 1890, **Pandora.** Catalog der Conchylien-Sammlung, **3:** 29, based on *Anatina truncata* Turton 1822, Conch. Ins. Brit., p. 46, pl. 4, fig. 6 [not a *Pandora*].

**tuomeyi** Gardner and Aldrich 1919, **Pandora (Clidiophora).** Proc. Acad. Nat. Sci. Philadelphia, **71:** 45, pl. 4, figs. 8, 10, 13 (Walker's Bluff, Bladen County, North Carolina, Waccamaw Formation [Miocene]; holotype, USNM 325502).

**uncifera** Pilsbry and Lowe 1932, **Pandora.** Proc. Acad. Nat. Sci. Philadelphia, **84:** 104, pl. 17, figs. 17–19 (Acapulco, Mexico, in 20 fathoms; holotype, ANSP 155632).

**unguiculus** Sowerby 1830, **Pandora.** [in] Broderip and Sowerby, Species Conchyliorum, **1**(1): *Pandora*, p. 3, figs. 16, 17 (locality unknown; types lost).

**vanwinkleae** Tegland 1933, **Pandora.** Univ. Calif. Publ., Bull. Dept. Geol. Sci., **23**(3); 113, pl. 7, figs. 1, 2 (in sandstone cliff on north side of Restoration Point, opposite Seattle, Section 12, T. 24, N, R. 2 E, Kitsap County, Washington; holotype, Coll. Invert. Paleo., Univ. Calif. No. 32114).

**vladivostokensis** Skarlato 1955, **Pandora,** [in Strelkov [ed.]. Atlas of the Invertebrates of the far-eastern seas of the USSR [in Russian], p. 198, pl. 53, fig. 10 (Japan Sea; types possibly in the Zoological Institute, Academy of Sciences, Leningrad).

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[1] Barnard (1964, p. 573) lists cotypes in South African Museum, Reg. No. A29743). The specimens may be paratypes.

**wajampolkensis** Slodkewitsch 1938, **Pandora.** Paleontology of USSR, Vol. 10, pt. 3, fasc. 19, Tertiary Pelecypoda from the Far East, Pt. 1, p. 272 [in Russian], Pt. 2, p. 126 [in English], pl. 59, figs. 1 a–b (Belogolovaya River, western coast of Kamchatka, Vayempolka series, Upper Miocene; holotype, Geological Museum, F. N. Chernyshev, No. 101/ c 754).

**washingtonensis** Weaver 1916, **Pandora.** Univ. Washington Publ. in Geol., **1**(1): 37–38, pl. 2, figs. 19, 20 (at locality 256 [University of Washington Paleontological Collection] in railway cuts on the O.-W. R. R. and N. Co. [Oregon-Washington = Union Pacific] one fourth mile northwest of Lincoln Creek Station in Section 27, T. 15 N, R. 3 W., Lowermost Oligocene; holotype, CAS 262).

**wardiana** A. Adams 1859, **Pandora.** Proc. Zool. Soc. London, pt. 3, p. 487 (hab. in littoribus Mantchuriae [Sunday Island, Coast of Mantchuria, in 20 fathoms]; holotype, BMNH, Reg. No. 1964468).

**yakatagensis** Clark 1932, **Pandora (Kennerlia).** Bull. Geol. Soc. Amer., **43**(3): 809, pl. 17, figs. 1, 2 (University of California Locality 3869 [near Fulton Creek, S of Yakataga River, Alaska], upper Oligocene; holotype, Invert. Coll'n, Museum of Paleontology, University of California, No. 30399).

**zealandica** 'Sowerby' Paetal 1883, **Pandora.** Catalog der Conchylien-Sammlung, p. 199, *nomen nudum.*

## REFERENCES

Boss, K. J. and A. S. Merrill. 1965. The Family Pandoridae in the Western Atlantic. Johnsonia **4**(44): 181–215, pls. 115–126.

Barnard, K. H. 1964. Contributions to the Knowledge of South African Marine Mollusca. Part V. Lamellibranchiata. Ann. South African Mus., **47**(3): 361–593.

Carpenter, P. P. 1864. Contributions toward a monograph of the Pandoridae. Proc. Zool. Soc. London, pt. 3, pp. 596–603.

Lamy, E. 1934. Revision des Pandoridae vivants du Muséum national d'Histoire naturelle de Paris. Jour. de Conchy., **78** (2): 95–125.

Moore, E. J. 1962. Conrad's cenozoic fossil marine mollusk type specimens at the Academy of Natural Sciences of Philadelphia. Proc. Acad. Nat. Sci. Philadelphia, **114:** 23–120.

Palmer, K. v. W. 1958. Type specimens of marine mollusca described by P. P. Carpenter from the West Coast (San Diego to British Columbia). Geo. Soc. Amer. Memoir 76, 376 pp , 35 pls.

Sherborn, C. D. 1940. Where is the —— Collection? Cambridge University Press, 148 pp.

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# SYMBIOTIC ERYCINACEAN BIVALVES

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## ABSTRACT

This paper is a summary of the occurrence of symbiotic behavior among representatives of the eulamellibranch superfamily Erycinacea. Individual cases of commensalistic, mutualistic, or even ectoparasitic and seemingly endoparasitic habits are presented and documentation is provided. The mollusks are discussed in relation to their hosts, and brief remarks are appended concerning the general causal nature of these associations.

## INTRODUCTION

During the preparation of a paper on a bivalve living attached to the stomatopod crustacean *Lysiosquilla* (Boss, 1965), I had occasion to consult the literature on commensal and parasitic lamellibranchs. The occurrence of these bivalves is widely documented in diverse publications, and it is the primary purpose of this paper to present a résumé of the scattered literature. In documenting the many known examples of commensalism and parasitism in the Bivalvia, I have limited the scope of this review to those involving the eulamellibranch superfamily Erycinacea. Cases of inquilinism, such as mytilids inhabiting sponges and ascidians or pectinids associated with corals, examples of specialized boring habits, such as *Lithophaga* or *Clavagella* in corals, or instances of true parasitism, such as the glochidium in the Unionidae, have been omitted. Further, no discussion of the definitions[1] of parasitism, mutualism, or commensalism will be made since the divisions among the phenomena are arbitrary and commonly the exact biological relationships between the bivalve and its host or hosts are unknown.

Most of the species of bivalves with known patterns of commensal or parasitic behavior appear to have a high degree of specificity. This specificity may be illusory, occasioned by the lack of detailed study or experimental observation. Thus, in a well-known species, *Mysella bidentata* (Montagu), a range of hosts, including annelids, sipunculids, and ophiuroids, has been documented, whereas in the majority of species only a single host has been mentioned. The relationships between the bivalves and their hosts are not well known. It appears that the water currents generated by the host are usually utilized by the mollusk in feeding. Further, some of the associations might well prove to be the means of efficient dispersal for the mollusks. In most examples it is difficult to detect what benefit, if any, is derived by the host animals.

Pelseneer (1909) has discussed the evolution of 2 diverse phylogenetic branches in the Erycinacea. The conchological studies of Chavan (1960) include a discussion of the evolution of hinge mechanisms in the Erycinacea, and considerations of anatomy have been presented by Pelseneer (1911), Kaspar (1913), Popham (1939; 1940), and Oldfield (1955; 1961; 1964) as well as numerous other authors who have discussed anatomical characters in their descriptions of new genera and species. The definitions of genera and, for that matter, of families and subfamilies in the superfamily are not precise. For this reason, the generic placement of some commensals has changed frequently. Information on the anatomy of those type-species, which are otherwise known only conchologically, is greatly needed in order to establish a more sound taxonomic foundation.

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[1] Definitions of the terms relating to symbiotic phenomena may be found in Pennak (1964).

In this review, each major group of hosts is considered. Original sources are included in the bibliography. The following is an alphabetical list of the erycinacean genera here discussed and the sections in which they are mentioned.

| | |
|---|---|
| *Achasmea* | Echiuroidea |
| *Aligena* | Annelida |
| *Ceratobornia* | Annelida, Arthropoda |
| *Cycladella* | Mollusca |
| *Cycladoconcha* | Echinodermata |
| *Devonia* | Echinodermata |
| *Divariscintilla* | Arthropoda |
| *Entovalva* | Echinodermata |
| *Ephippodonta* | Porifera, Coelenterata, Arthropoda |
| *Fronsella* | Sipunculoidea |
| *Galeomma* | Coelenterata |
| *Jousseaumiella* | Coelenterata, Sipunculoidea |
| *Kellia* | Porifera, Bryozoa, Mollusca, Echinodermata, Arthropoda |
| *Lasaea* | Mollusca, Echinodermata |
| *Lepton* | Annelida, Echinodermata, Arthropoda |
| *Libratula* | Coelenterata |
| *Marikellia* | Porifera, Mollusca |
| *Montacuta* | Sipunculoidea, Bryozoa, Echinodermata |
| *Mylitta* | Echinodermata |
| *Mysella* | Sipunculoidea, Annelida, Mollusca, Echinodermata |
| *Nipponomontacuta* | Coelenterata |
| *Parabornia* | Arthropoda |
| *Peregrinamor* | Arthropoda |
| *Phlyctaenachlamys* | Arthropoda |
| *Potidoma* | Sipunculoidea, Annelida |
| *Pseudopythina* | Annelida, Arthropoda |
| *Rochelfortia* | Sipunculoidea, Arthropoda |
| *Scintillona* | Echinodermata |
| *Scioberetia* | Echinodermata |
| *Serridens* | Mollusca |
| *Sphaerumbonella* | Coelenterata |
| *Synapticola* | Echinodermata |
| *Thyreopsis* | Coelenterata |
| *Vasconiella* | Arthropoda |

## PORIFERA

Cotton and Godfrey (1938) recorded *Marikellia vincentensis*[2] from the Gulf of St. Vincent, Australia, in the hollows of an unnamed sponge. Three species of *Ephippodonta*, from Australia: *E. macdougalli* Tate, *E. lunata* Tate, and *E. turnbullae* Buick and Bowden, live in association with an unnamed, orange-colored sponge at the opening of the muddy burrows of the shrimp *Axius* (Tate, 1889; Matthews, 1893; Buick and Bowden, 1951).

## COELENTERATA

From unnamed corals, Adams (1868) described *Thyreopsis coralliophila* from Mauritius and Pease (1865) named *Libratula plana* from the Central Pacific. These species have been cited by Franc (1960) as members of the genus *Galeomma*.

Yamamoto and Habe (1961) established *Nipponomontacuta actinariophila*, which was found on an unnamed sea anemone off Honshu, Japan. Coen (1933) described a new genus and species, *Sphaerumbonella brunelli*, as occurring in a burrow, which was thought to be that of an annelid, at the base of a madreporarian coral at Massaua, Eritrea, on the Red Sea.

Kuroda (1946) figured and described *Ephippodonta murakamii* from Japan, and

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[2] Dell (1964) included *Marikellia* Iredale in the synonymy of *Kellia* Turton.

Arakawa (1960) presented ecological data which indicate that this species of *Ephippondonta*, unlike the Australian species, lives attached to the deep sea coral *Dendrophyllia cribosa* Milne-Edwards and Haime.

From the Ceylon coast in the Gulf of Manaar, Bourne (1906) named 2 species of the genus *Jousseaumia*, later renamed *Jousseaumiella* (Bourne, 1907). The 2 species, *J. heteropsammiae* and *J. heterocyathi*, live in the burrows of the sipunculid *Aspidosiphon*, in the corals *Heteropsammia michelini* Milne-Edwards and Haime and *Heterocyathus aequicostatus* Milne-Edwards and Haime, respectively. To one of these species of *Jousseaumiella*, Bouvier (1894; 1895) applied the name *Kellia deshayesii* and Shipley (1903) referred to them as unknown species of *Mysella*.

## SIPUNCULOIDEA

Pelseneer (1928) listed some examples of the symbiotic relationships between sipunculids and mollusks. *Montacuta* (*Litigiella*) *glabra* (Fischer), which according to Pelseneer (1911) is synonymous with *Erycina cuenoti* Lamy and *Montacuta perezi* Pelseneer, has been found on *Sipunculus nudus* Linnaeus at Arcachon, France (Pelseneer, 1909; Franc, 1960). In Japan, *Fronsella ohshimai* Habe may attach on the skin near the anus of *S. nudus* (Habe, 1964). Species associated with *Golfingia vulgare* (de Blainville) on the coast of France include *Mysella bidentata* and *Potidoma clarkiae* (Clark) (Pelseneer, 1925). Deroux (1961) placed *Lepton clarkiae* in the genus *Potidoma*. In England, *M. bidentata* and *P. clarkiae* have been reported in association with *Phascolosoma pellucidum* (Orton, 1923; Winckworth, 1924a) and with *P. elongatum* Keferstein (Gardiner, 1928; Salisbury, 1932; Popham, 1940).

A more complex commensal relation occurs among the species of *Jousseaumiella*. Two species of this genus have been recorded in association with the corals *Heteropsammia* and *Heterocyathus* in the Gulf of Manaar by Bourne (1906) where they live in the burrows of *Aspidosiphon*, sometimes imbedded in the skin of the posterior portions of the sipunculid. From Indonesian waters, Knudsen (1944) described *Jousseaumiella concharum*, a protandric hermaphrodite with brood protection, which attaches to the *Mitra* shell used by species of *Aspidosiphon* or *Phascolion*.

In Europe, *Phascolion strombi* (Montagu) is the center of a complex ethological relationship (Perez, 1924; 1925). This sipunculid inhabits discarded shells of gastropods including *Nassarius*, *Murex*, and *Aporrhais*. In the example given by Perez, *P. strombi* lived in the shells of *Turritella communis* Risso and *Zizyphinus* [=*Calliostoma*] *conuloides* Lamarck. The bivalve *Montacuta phascolionis* Dautzenberg was attached at the orifice where the sipunculids generated water currents. In addition, the small ectoparasitic gastropod *Odostomia* (*Auristomia*) *perezi* Dautzenberg, a syllid polychaete, *Langerhansia cornuta* (Rathke), and the endoproct bryozoan *Loxosoma* may also be in the association.

In the western Atlantic, *Phascolion strombi* lives in the empty shells of *Nassarius trivittatus* (Say) and *Eupleura caudata* (Say). Hampson (1964) showed that *Rochefortia* (*Pythinella*) *cuneata* (Verrill and Bush) lives in association with this sipunculid, much as *Montacuta phascolionis* does in Europe.

## ECHIUROIDEA

Habe (1962) described and figured *Achasmea thalassemicola*, attached to the body and proboscis of the echiuroid *Thalassema mucosum* Ikeda, from the intertidal zone of Tomoe Bay, Tomioka, Japan.

## BRYOZOA

Madsen (1949) recorded an association between *Kellia rubra* (Montagu) and an unnamed bryozoan in Iceland.

Perez (1924) showed that the endoproct *Loxosoma* may be involved in the complex commensal relationship between *Montacuta phascolionis* and *Phascolion strombi*.

## ANNELIDA

Stimpson (1855) described *Lepton* [*Ceratobornia*] *longipes* from South Carolina and noted that it lived in "holes of marine worms and fossorial crustaceans." *Lepton squamosum* (Montagu) and an unnamed species of *Kellia* were listed from annelid burrows by Fischer (1887). The occurrence of *Mysella bidentata* in the burrows of *Nereis* has been reported by Winckworth (1923) and Orton (1923). Anthony (1916) cited an unnamed species of *Montacuta* in the tubes of *Eunereis longissima* (Johnston) at Boulogne. In the eastern Pacific, *Pseudopythina rugifera* (Carpenter), well-known as an ectoparasite of the crustacean *Upogebia*, lives attached by its byssus to the ventral surface of the polychaete worm, or sea mouse, *Aphrodite* (Oldroyd, 1924; MacGinitie and MacGinitie, 1949). For the European species, *Lepton subtrigonum* Jeffreys, Deroux (1961) established the genus *Potidoma*, which also includes *Lepton clarkiae*, a commensal of sipunculids. *Potidoma subtrigona* attaches byssally to the medial segments of the ventral surface of the polychaete *Polydontes maxillosus* (Ranzani). In Barnstable Harbor, Massachusetts, *Aligena elevata* Stimpson has been found attached to the lower end of *Clymenella torquata* (Leidy) (Sanders *et al.*, 1962).

## MOLLUSCA

AMPHINEURA. Kelsey (1902) found *Serridens oblonga* (Carpenter) nestling under the mantle or clinging to the shell of *Ischnochiton conspicuus* (Carpenter) at Point Loma and Pacific Beach, California. In adding *Ischnochiton magdalenensis* Hinds to the list of known hosts for *S. oblonga*, Burch and Burch (1944) confirmed the observations of Kelsey and noted that the commensals could also be found among the gills and on the bottom of the foot of the chitons. In their study on the fauna of Monterey Bay, California, Smith and Gordon (1948) recorded *S. oblonga* on *Ischnochiton heathiana* (Berry).

GASTROPODA. *Lasaea scalaris* Philippi has been found attached to the aperture of *Turricula teresiae* Tenison-Woods in South Australia by Verco (1913), who suggested that a possible commensal relationship existed between the 2 species. *Kellia rubra* (Montagu) has been found among the tubes of *Vermetus corallinaceus* Tomlin at Oudekrall, South Africa (Barnard, 1964). *Mysella bidentata* (Montagu) has been associated with *Akera nana* Jeffreys and *A. bullata* Müller (Winckworth, 1923).

BIVALVIA. Members of the genus *Lasaea* often nestle among the byssi of mytilids (Keen, 1938). Haas (1942) reported a specificity in these habits within *L. cistula* Keen and *L. subviridis* Dall. Both species preferably live in the shell or within the byssal strands of *Brachidontes* (*Hormomya*) *multiformis* Carpenter in California, and are not found in the byssus of *Mytilus californianus* Conrad. North of Point Conception, at the end of the range of *B. multiformis*, both species of *Lasaea* occur in the byssus of *M. californianus*. Haas also reported that in Peru, *L. miliaris* Philippi lives in the byssus of *Brachidontes granulatus* Hanley. A similar situation obtains among the species of *Marikellia* [=*Kellia*] in Australia where Laseron (1956) has reported that certain species are found among the byssus of the mussel *Trichomya hirsuta* (Lamarck).

Carpenter (1865) recorded a number of species, including those of his genus *Cycladella* on the shells of *Chama* and *Spondylus*. The species were nestlers and no indication of commensal relationships was evident.

Packard (1918) found *Kellia laperousii* Deshayes in pholadid borings in San

Francisco Bay, and Pelseneer (1922) found *Mysella bidentata* on *Barnea candida* (Linnaeus) in Europe.

## ECHINODERMATA

ECHINOIDEA. Many reports in the literature document the occurrence of *Montacuta substriata* (Montagu) and *M. ferruginosa* (Montagu) with various echinoids. Jeffreys (1863) and Pelseneer (1925) listed the species of echinoids upon which *M. substriata* could be found. Among them were: *Spatangus purpureus* Müller (=*S. meridionalis* Risso), *Cidaris cidaris* (Linnaeus), *Echinocardium flavescens* (Müller), *Brissopsis lyrifera* (Forbes), and *Echinus esculentus* Linnaeus. *M. substriata* attaches itself by 2 or 3 byssal threads to the oral spines of *S. purpureus*. This behavior has been reported from numerous European localities (Brusina, 1865; Norman, 1891a; Grieg, 1896; Madsen, 1949; Popham, 1940; Pelseneer, 1925; Deroux, 1961). Also, Vayssière (1920) found *Lasaea rubra* on *Spatangus*.

Certainly the most remarkable situation which involves the commensals of *S. purpureus* is that reported by Marshall (1891). When both *Montacuta substriata* and *M. ferruginosa* live attached to the urchin, the specimens of *M. substriata* attach only to the spines on the ventral region of the host whereas individuals of *M. ferruginosa* are on the dorsal spines. Outside the range of *M. substriata*, *M. ferruginosa* is found on both oral and aboral regions of its host. This example is a fine illustration of Gause's law of competitive exclusion.

As early as 1848, Lovén recorded the occurrence of *M. ferruginosa* on *Brissopsis lyrifera* in Sweden, and Giard (1886) found it on *Echinocardium cordatum* (Pennant) on the French coast. Marshall (1891) noted *M. ferruginosa* living in the burrow of *E. cordatum* at Torbay, England, while in another population he discovered the bivalves attached to the spines of the urchin. The larger or more adult specimens of *M. ferruginosa* live opposite the anal siphon of the urchin but younger individuals are attached to the urchin's oral spines (Allen and Todd, 1900; Salisbury, 1932; Winckworth, 1924a; Moore, 1933; Popham, 1940; Deroux, 1961; Morton, 1962). Similarly, at Port Philipp, Victoria, Australia, *Montacuta semiradiata* Tate lives on the spines of *E. cordatum* (Tate, 1889; Cotton and Godfrey, 1938; Franc, 1960). In Japan, *Montacuta echinocardiophila* has recently been described by Habe (1964) as attaching to *E. cordatum*.

The Antarctic spatangoid, *Abatus cavernosus* (Philippi), previously referred to such genera as *Spatangus*, *Tripylus*, and *Hemiaster*, is host to a number of commensals. Dall (1876) described the first of these as *Lepton parasiticum* from the ambulacra or the surface of the test of an unnamed species of spatangoid dredged in Royal Sound, Kerguelen Island. Smith (1877) substantiated Dall's discovery and indicated that the host species is *A. cavernosus*. Later Bernard (1896) described the curious *Scioberetia australis* which lives commensally in the brood pouches of *A. cavernosus*, and then Grieg (1929) named *Montacuta christenseni*, another commensal bivalve living attached to the spines around the peristome on the ventral side of the sea urchin. Mortensen (1936; 1951) mentioned an unnamed *Lepton*, attaching in great numbers to *A. cavernosus* and filling up the petals and apical system of the urchin. According to him, this species is not the *L. parasiticum* of Dall.

Soot-Ryen (1959) referred a species of *Lepton* to *parasiticum* of Dall which was found living on *Tripylaster philippi* Gray in southern Chile. Dell (1964) has indicated that the species found by Soot-Ryen could not be the same as *L. parasiticum*.

HOLOTHUROIDEA. Semper (1868) made early mention of the occurrence of ectocommensal bivalves on synaptids when he recorded but did not describe a small pelecypod living on *Protankyra* *similis* (Semper) in the Philippines. The first documented case of "parasitism" of bivalves in holothurians was presented by Voeltzkow (1890) who named and described *Entovalva mirabilis*, a species living in the oesophagus of *Synapta* [*Leptosynapta*] *ooplax* von Marenzeller [3]. Schepman and Nierstrasz (1913) added to the original description and gave ecological data on *E. mirabilis*.

*Entovalva* (*Devonia*) *perrieri* was described by Malard (1903), who found the ectoparasite on the posterior portions of the body of the synaptid *Leptosynapta inhaerens* (Müller) at Saint-Vaast-la-Hougue, France. He erected the genus *Synapticola* for the species but since this name was preoccupied in the Crustacea, Winckworth (1930) proposed *Devonia*. Anthony (1916) studied the morphology of *E. perrieri* in detail, noted its relationship to *E. mirabilis*, and considered the species a member of *Entovalva*. He found that the small bivalve was usually attached to the posterior portions of the body of the synaptid but occasionally was found at the base of the tentacles of its host. He also indicated that the glochidial-type larval form found by Herpin (1915) at Cherbourg may be a stage in the life history of *E. perrieri*. Clench and Aguayo (1931) recorded *E. perrieri* at Woods Hole, Massachusetts, on *L. inhaerens* and thus extended the known range of the ectoparasite to the western Atlantic. In England, Popham (1940) discussed some aspects of the morphology of the mollusk and noted that it attached to and progressed over the surface of the holothurian by means of its foot.

Another species of *Entovalva*, *E. semperi* Ohshima, occurs in the Pacific Ocean and was reported by Ohshima (1929; 1930; 1931) from Kyushu, Japan. This species infests 2 apodous holothurians, *Leptosynapta inhaerens*, the usual host for *Entovalva*, and *Protankyra bidentata* (Woodward and Barrett). From Isigaki Island in the Ryukyu Islands, Kawahara (1942) found another *Devonia*, *E.* (*D.*) *ohshimai* attached to the body wall of *Leptosynapta ooplax* (von Marenzeller).

A fifth species of *Entovalva*, *E. major*, was described by Bruun (1938) from the Biological Station at Ghardaqa, Egypt, on the Red Sea. This species was associated with the aspidochiroten *Mertensiothuria fuscocineria* (Jaeger) [=*Holothuria curiosa* (Ludwig)]. On the basis of circumstantial evidence, Bruun suggested that *E. major* probably lives in the cloaca of the holothurian.

Spärck (1931) established the new genus and species, *Cycladoconcha amboinensis*, from Indonesian waters, where it lives in small pouches in the oesophagus of the apodous holothurian *Patinapta laevis* (Bedford). This peculiar endoparasitic relationship is very similar to that of *Entovalva mirabilis* in the oesophagus of *Patinapta crosslandi* mentioned previously. *Cycladoconcha* is closely related to *Entovalva*.

*Montacuta donacina* (Wood) and *M. percompressa* Dall have been found on *Leptosynapta inhaerens* (Bateson, 1923; Gray, 1933; *M. donacina* has also been found on *Labidoplax digitata* (Montagu) (Franc, 1960).

Morton (1957) discussed the morphology and parasitic habits of *Scintillona zelandica* (Odhner) on the synaptid *Trochodota dendyi* Mortensen, in New Zealand.

OPHIUROIDEA. At Salcombe, England, *Mysella bidentata* (Montagu) lives in association with the brittle stars *Ophiocnida brachiata* (Montagu) and *Amphiura filiformis* (Müller) (Winckworth, 1923). At Plymouth, Orton (1923) found *M. bidentata* in the vicinity of the disc of *O. brachiata* and reported a third organism in this commensalistic association, namely, the polynoid polychaete

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[3] Spärck (1931) has indicated that the holothurian in which *E. mirabilis* lives is *Patinapta crosslandi* (Heding) not *Synapta ooplax* von Marenzeller.

*Harmothoë lunulata* (delle Chiaje). Popham (1940), in her study of the mantle cavity of the Erycinacea, noted that *M. bidentata* does not attach itself to its ophiuroid host.

## ARTHROPODA

DECAPODA. Living along the muddy burrows of the shrimp *Axius plectorhychus* (Strahl), are the 3 Australian species of *Ephippodonta: E. macdougalli* Tate, *E. lunata* Tate, and *E. turnbullae* Buick and Bowden (Tate, 1889; Buick and Bowden, 1951). A sponge may also live along with these species in the burrow. In addition to the species of *Ephippodonta*, 3 species of *Mylitta: M. tasmanica* Tenison-Woods, *M. gemmata* Tate, *M. deshayesiana* d'Orbigny, as well as an unnamed species of *Kellia*, may also be found in the burrows of *Axius* (Matthews, 1893; Cotton and Godfrey, 1938). The morphology of *Ephippodonta* has been discussed by Woodward (1893).

In England, *Lepton squamosum* (Montagu) lives in the burrows of *Upogebia deltaura* (Leach) and *U. stellata* (Montagu) (Norman, 1891a; Winckworth, 1924 a and b; Salisbury, 1932), and in France, *Lepton nitidum* Turton has been found attached by its byssus to *U. deltaura* (Pelseneer, 1925).

One of the best known cases of a bivalve attached to a crustacean is that of *Pseudopythina rugifera* (Carpenter) which affixes by means of it byssus to the ventral portions of the abdominal segments of the blue mud shrimp of western North America, *Upogebia pugettensis* (Dana). Stimpson (1857) first noted this relationship; it was subsequently reported by, among others, Norman (1891b), Harrington and Griffin (1898) and Dall (1899), who pictured the attached bivalve. The *Lepton rude* described by Whiteaves (1880) is synonymous with *P. rugifera*. MacGinitie and MacGinitie (1949) reported that *P. rugifera* may also be encountered on the venter of the sea mouse *Aphrodite* even more often than on the mud shrimp. From Japan, Shôji (1938) described *Peregrinamor ohshimai*, a galeommatid commensal, which attaches by its byssus to the ventral portion and along the median line of the cephalothorax of the burrowing shrimp *Upogebia major* (de Haan).

Stimpson (1855) discovered *Lepton longipes*, which he noted living in the "holes of marine worms and fossorial crustaceans" in South Carolina. Norman (1891a) identified some of the hosts of *L. longipes* as *Callianassa major* Say and *Upogebia affinis* (Say). Dall (1899) placed *L. longipes* in the genus *Ceratobornia*. Oldroyd (1924) added that both *Pseudopythina compressa* Dall and *P. myaciformis* Dall were also commensal with crustaceans. *Rochefortia pedroana* Dall attaches to the hairs of the legs and the ventral regions among the gills of the large sand crab, *Blepharipoda occidentalis* Randall in California (Burch and Burch, 1944; Emerson, 1944). Incidentally, the nonerycinacean bivalves *Mytilus edulis* Linnaeus and *Cerastoderma edule* (Linnaeus) have been found attached to the abdomen of *Carcinides maenas* (Linnaeus) (Fischer, 1930; Wolff, 1959).

STOMATOPODA. Kuroda (1937) illustrated *Pseudopythina subsinuata* (Lischke) attached by its byssus to the first abdominal segment of *Squilla oratoria* de Haan from Japan. From the area of the Great Barrier Reef in Australia, Popham (1939) described *Phlyctaenachlamys lysiosquillina* which lives commensally in the burrows of *Lysiosquilla maculata* (Fabricius). Powell (*in* Morton, 1957) suggested that *Divariscintilla maoria* Powell of New Zealand, which is conchologically similar to *Vasconiella* of the eastern Atlantic (Kisch, 1958), may live attached to a species of *Lysiosquilla*. Moore (1961) noted the presence of a small bivalve, which he tentatively referred to as *Lepton*, on *Lysiosquilla scabricauda* (Lamarck) in Mississippi; Boss (1965) has described this species as *Parabornia squillina* found attached to the ventral surface of the abdomen and thorax of *L. scabricauda* from the Caribbean coast of Panama.

## CONCLUSION

Some general principles may be stated from even a casual analysis of the extensive list of individual commensals and their hosts. The hosts are exclusively invertebrates, and certain groups of invertebrates are preferred. Two common ecological or behavioral factors may be responsible for these associations. Most of the hosts are slow moving, almost sessile forms, which burrow in sandy or muddy bottoms, and further, most of them obtain their food by filter feeding. The relative immobility of the hosts facilitates simple attachment or association by the commensal and the currents created by the processes of filter feeding generate a favorable environment for the small mollusks, which are themselves filter feeders. Natant or more mobile hosts, such as the higher crustaceans, carry the small bivalves attached ventrally in a relatively protected position. The relationships between erycinacean bivalves and their hosts appear to be predominantly commensalistic, and no evidence exists of deleterious or pathologic effects on the hosts, even when the mollusks live inside the host or attach directly to its epidermis. In assuming a commensalistic existence, the erycinaceans have evolved toward highly specialized habits with concomitant morphological adaptations, including the enclosure of the shell by the mantle and the reduction of the shell.

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## LITERATURE CITED

ADAMS, H., 1868, Further descriptions of new species of shells collected at Mauritius by Geoffrey Nevill, Esq. Proc. zool. Soc. London, pt. 1, p 12-14, pl. 4.

ALLEN, E. J. and E. A. TODD, 1900, The fauna of the Salcombe Estuary. J. mar. biol. Ass. U. K., 6: 151-217.

ANTHONY, R., 1916, Contribution á l'étude de l'*Entovalva* (*Synapticola*) *perrieri* Malard, mollusque acéphale commensal des synaptes. Arch. Zool. expér. et générale, 55: 375-391,pls. 6-7, 8 text-figs.

ARAKAWA, K. Y., 1960, Ecological observations on an aberrant lamellibranch, *Ephippodonta murakamii* Kuroda. Venus, 21: 50-60, pls. 7-8.

BARNARD, K. H., 1964, Contributions to the knowledge of South African marine Mollusca. Part 5. Lamellibranchiata. Ann. S. Afr. Mus., 47: 361-593, 39 figs.

BATESON, G., 1923, [no title]. Proc. malac. Soc. London, 15: 266-267.

BERNARD, F., 1896, *Scioberetia australis*, type nouveau des lamellibranches. Bull. Sci. France et Belgique, 27: 364-395, pls. 13-15.

BOSS, K. J., 1965. A new mollusk (Bivalvia, Erycinidae) commensal on the stomatopod crustacean *Lysiosquilla*. American Museum Novitates, no. 2215, 11pp., 3 figs.

BOURNE, G. C., 1906, On *Jousseaumia*. A new genus of eulamellibranches commensal with the corals *Heterocyanthus* and *Heteropsammia*. In Herdman, W. A., ed. Rept. Pearl

Oyster Fisheries of the Gulf of Manaar. 37th Suppl. Rep., Part 5, 243-266, 3 pls.

_______, 1907, Note to correct the name *Jousseaumia*. Proc. malac. Soc. London, 7: 260.

BOUVIER, E. L., 1894, Un nouveau cas de commensalisme: association de vers du genre *Aspidosiphon* avec des polypes madréporaires et un mollusque bivalve. C. R. Acad. Sci. Paris, 119: 96-98.

_______, 1895, Le commensalisme chez certains polypes madréporaires. Ann. Sci. nat. Zool., sér. 7, 20: 1-32, 1 pl., 25 figs.

BRUSINA, S., 1865, Conchiglie dalmati inedite. Verhandl. zool. bot. Gesellschaft, Wien, 15: 1-42.

BRUUN, A. F., 1938, A new entocommensalistic bivalve, *Entovalva major* n. sp., from the Red Sea. Vidensk. Medd. Dansk Naturh. Foren., 102: 163-167, 1 fig.

BUICK, W. G. and W. M. BOWDEN, 1951, A new Australian shell. S. Aust. Nat., 26: 5-6, 1 fig.

BURCH, J. Q. and T. BURCH, 1944, [no title]. Minutes, Conchol. Club S. Calif., (40): 15-16.

CARPENTER, P. P., 1865, Diagnoses of new species and a new genus from the Reigen Mazatlan collection. Proc. zool. Soc. London, pt. 3, p 268-273.

CHAVAN, A., 1960, Remarques sur la charnière des Erycinacea et des Cyamiacea. Bull. Soc. Geol. France, sér. 7, 1: 712-718.

CLENCH, W. J. and C. G. AGUAYO, 1931, *Entovalva* (*Devonia*) *perrieri* (Malard) in the western Atlantic. Occ. Paps. Boston Soc. nat. Hist., 8: 5-8.

COEN, G., 1933, Un nuovo lamellibranco eritreo. Boll. di pesca, di piscicoltura e di idrobiologia, Roma, 9: 206-208, 1 pl.

COTTON, B. C. and F. K. GODFREY, 1938, The Mollusca of South Australia. Pt. 1. The Pelecypoda, 314 p, 340 figs.

DALL, W. H., 1876, Contributions to the natural history of Kerguelen Island. Bull. U. S. Nat. Mus., 3: 42-48.

_______, 1899, Synopsis of the Recent and Tertiary Leptonacea of North America and the West Indies. Proc. U. S. Nat. Mus., 21: 873-897, pls. 87-88.

DELL, R. K., 1964, Antarctic and subantarctic mollusca: Amphineura, Scaphopoda and Bivalvia. Discovery Rept., 33: 93-250, 6 pls.

DEROUX, G., 1961, Rapports taxonomiques d'un leptonacé non décrit "*Lepton subtrigonum*" Jeffreys (*nomen nudum* - 1873). Cahiers Biologie Marine, Roscoff, 2: 99-153, 1 pl., 18 figs.

EMERSON, W. K., 1944, [no title]. Minutes, Conchol. Club S. Calif., (41): 20.

FISCHER, P., 1887, Manuel de Conchyliologie. Paris, 1369 p, 23 pls., 1158 figs.

FISCHER, P. H., 1930, Lamellibranches fixés sous l'abdomen d'un crabe. J. Conchyl., 74: 39-41, 4 figs.

FRANC, A., 1960, Classe des Bivalves. *In* Grassé, Traité de Zoologie, 5: 1845-2133.

GARDINER, A., 1928, Notes on British Mollusca. J. Conchol., 18: 245-250.

GIARD, A., 1886, Les habitants d'une plage sablonneuse. Bull. Sci. Nord. France, sér. 2, 17: 187-196.

GRAY, G. M., 1933, Observations on *Montacuta percompressa* Dall. Nautilus, 46: 76-79.

GRIEG, J. A., 1896, Bidrag til Kundskaben om Vestlandets mollusker. Bergens Mus. Aarbog, (10): 14.

_______, 1929, Echinodermata from the Palmer Archipelago, South Shetlands, South Georgia and the Bouvet Islands. Det Norske Videnskaps-Akad. Oslo, Sci. Results Norwegian Antarctic Exp., 1927-1928, 1928-1929, (2): 16 p.

HAAS, F., 1942, The habits of life of some west coast bivalves. Nautilus, 56: 30-33.

HABE, T., 1962, *Achasmea thalassemicola* sp. nov., a new commensal bivalve found in an echiuroid, *Thalassema mucosum* Ikeda. Venus, 22: 117-119, figs. 1-3.

________, 1964, Two commensal bivalves from the west coast of Kyushu, Japan. Venus, 23 (3): 137-139, pl. 8.

HAMPSON, G. R., 1964, Redescription of a commensal pelecypod, *Rochefortia cuneata*, with notes on ecology. Nautilus, 77: 125-128, fig. 1 a-f.

HARRINGTON, N. R. and B. B. GRIFFIN, 1898, Notes upon the distribution and habits of several Puget Sound invertebrates. Trans. New York Acad. Sci., 16: 152-165.

HERPIN, R., 1915, Un mollusque énigmatique commensal des synaptes. Bull. Inst. Océanogr., Monaco, (302): 1-5.

JEFFREYS, J. G., 1863, British Conchology. Van Voorst, London, Vol. 2, 465 p, 8 pls.

KASPAR, J., 1913, Beiträge zur Kenntnis der Familie der Eryciniden und Carditiden. Zool. Jahrb., (Suppl. 13), 4: 545-625.

KAWAHARA, T., 1942, On *Devonia ohshimai* sp. nov., a commensal bivalve attached to the synaptid *Leptosynapta ooplax*. Venus, 11: 153-164, figs. 1-2.

KEEN, A. M., 1938, New pelecypod species of the genera *Lasaea* and *Crassinella*. Proc. malac. Soc. London, 23: 18-32, pl. 2.

KELSEY, F. W., 1902, [no title]. Nautilus, 15: 144.

KISCH, B. S., 1958, *Vasconiella jeffreysiana* (P. Fischer). Proc. malac. Soc. London, 33: 21-24, pl. 3.

KNUDSEN, J., 1944, A gephyrean, a polychaete and a bivalve (*Jousseaumiella concharum* nov. sp.) living together (commensalistically) in the Indo-Malayan seas. Vidensk. Medd. Dansk Naturh. Foren., 108: 15-24, 6 figs.

KURODA, T., 1937, The habit of "*Kellia*" *subsinuata* Lischke [in Japanese]. Venus, 7: 188-189, 2 figs.

________, 1946, [no title; in Japanese]. Venus, 14: 39-41.

LASERON, C. T., 1956, A revision of the New South Wales Leptonidae. Rec. Aus. Mus., 24: 7-22, figs. 1-27.

LOVÉN, S., 1848, Bidrag till Kännedomen om Utvecklingen af Mollusca Acephala Lamellibranchiata. K. Vetensk. Akad. Handl., 2: 329-435, pls. 10-15.

MacGINITIE, G. E. and N. MacGINITIE, 1949, Natural history of marine animals. McGraw-Hill, New York, 473p, 282 figs.

MADSEN, F. J., 1949, Marine Bivalvia. The Zoology of Iceland, 4: 116 p, 12 figs.

MALARD, A. E., 1903, Sur un lamellibranche nouveau, parasite des synaptes. Bull. Mus. Hist. nat. Paris, 9: 342-346.

MARSHALL, J. T., 1891, The habitat of *Montacuta ferruginosa*. Jour. Conchol., 6: 399-404.

MATTHEWS, E. H., 1893, On the habit of the genus *Ephippodonta* (Tate). Conchologist, 2: 144-145.

MOORE, D. R., 1961, The marine and brackish water Mollusca of the state of Mississippi. Gulf Research Reports, 1 (1): 1-58.

MOORE, H. G., 1933, A comparison of the sand fauna of Port Erin Bay in 1900 and in 1933. Proc. malac. Soc. London, 20: 285-294.

MORTENSEN, T., 1936, Echinoidea and Ophiuroidea. Discovery Rept., 12: 199-348, 9 pls.

________, 1951, Monograph of the Echinoidea. Spatangoida II. Copenhagen, 593 p, 286 figs., 64 pls.

MORTON, J. E., 1957, The habits of *Scintillona zelandica* (Odhner) 1924 (Lamellibranchia: Galeommatidae). Proc. malac. Soc. London, 32: 185-188.

________, 1962, Habit and orientation in the small commensal bivalve mollusc, *Montacuta ferruginosa*. Anim. Behav., 10: 126-133.

NORMAN, A. M., 1891a, *Lepton squamosum* (Montagu), a commensal. Ann. Mag. nat. Hist., ser. 6,7: 276-278.

________, 1891b, Additional notes on the mollusks *Lepton* as a commensal and on the crustacean genus *Bathynectes*. Ann. Mag. nat. Hist., ser. 6,7: 387-388.

OHSHIMA, H., 1929, On a rare bivalve, *Entovalva semperi* n. sp. creeping on the body surface of apodous holothurians [in Japanese]. Dobutsug. Zasshi, Tokyo, 42: 364-366.

________, 1930, Preliminary note on *Entovalva semperi* sp. nov., a commensal bivalve living attached to the body of a synaptid. Annot. Zool. Japan, 13: 25-27, pl. 2.

________, 1931, On *Entovalva semperi* Ohshima, an aberrant commensal bivalve. Venus, 2: 161-177, pls. 5-6.

OLDFIELD, E., 1955, Observations on the anatomy and mode of life of *Lasaea rubra* (Montagu) and *Turtonia minuta* (Fabricius). Proc. malac. Soc. London, 31: 226-249.

________, 1961, The functional morphology of *Kellia suborbicularis* (Montagu), *Montacuta ferruginosa* (Montagu) and *M. substriata* (Montagu), (Mollusca, Lamellibranchiata). Proc. malac. Soc. London, 34: 255-295.

________, 1964, The reproduction and development of some members of the Erycinidae and Montacutidae (Mollusca, Eulamellibranchiata). Proc. malac. Soc. London, 36: 79-120, 21 figs.

OLDROYD, I. S., 1924, Marine shells of Puget Sound and vicinity. Publ. Puget Sound biol. Stat., 4: 272 p, 49 pls.

ORTON, J. H., 1923, Some new commensals in the Plymouth district. Nature, 112: 861, 1 fig.

PACKARD, E. L., 1918, Molluscan fauna from San Francisco Bay. Univ. Calif. Publ. Zool. (Berkeley), 14: 199-452, pls. 14-60.

PEASE, W. H., 1865, Description of new genera and species of marine shells from the islands of the Central Pacific. Proc. zool. Soc. London, pt. 2, p 512-517.

PELSENEER, P., 1909, Phylogénie des Lamellibranches commensaux. Bull. Acad. Belg. (Sci.), (12): 1144-1150.

________, 1911, Les lamellibranches de l'expédition du Siboga. Partie Anatomique. Siboga-Exped., Monogr. 53a, 125 p, 26 pls.

________, 1922, [no title]. Ann. Soc. Roy. Zool. Malac. Belgique, 52: 149.

________, 1925, Un Lamellibranche commensal de Lamellibranche et quelques autres Lamellibranches commensaux. Wimereux Trav. Stat. Zool., 9: 164-182.

________, 1928, Les parasites des mollusques parasites. Bull. Soc. Zool. Fr., 53: 158-189.

PENNAK, R. W., 1964, Collegiate Dictionary of Zoology. Ronald Press, New York, 583 p.

PEREZ, C., 1924, Le complexe éthologique de la Turritelle et du *Phascolion strombi*. Bull. Soc. Zool. Fr., 49: 341-343.

________, 1925, Sur le complexe éthologique du *Phascolion strombi*. Bull. Soc. Zool. Fr., 50: 74-76, 3 figs.

POPHAM, M. L., 1939, On *Phlyctaenachlamys lysiosquillina* gen. and sp. nov. a lamellibranch commensal in the burrows of *Lysiosquilla maculata*. Sci. Rep., Great Barrier Reef Exp., 6: 61-84.

________, 1940, The mantle cavity of some of the Erycinidae, Montacutidae, and Galeommatidae with special reference to the ciliary mechanisms. J. mar. biol. Ass. U. K., 24: 549-586.

SALISBURY, A. E., 1932, On *Lepton squamosum* (Montagu) and *Montacuta ferruginosa* (Montagu) and some other molluscs observed at the Salcombe estuary, Devon. Proc. malac. Soc. London, 20: 100-103, pl. 9b.

SANDERS, H. L., GOUDSMIT, E. M., MILLS, R. L., and G. E. HAMPSON, 1962, A study of the intertidal fauna of Barnstable Harbor, Massachusetts. Limn. and Oceanogr., 7 (1): 63-79.

SCHEPMAN, M. M. and H. F. NIERSTRASZ, 1913, Parasitische und kommensalistische Mollusken aus Holothurien. *In* Voeltzkow, Reise in Ostafrika in den Jahren 1903-1905, 4: 384-416, pls. 27-30.

SEMPER, G., 1868, Reisen im Archipel der Philippinen. II. Teil. 1. Die Holothurien. Leipzig. 288 p.

SHIPLEY, A. E., 1903, Report on the Gephyrea collected by Professor Herdman at Ceylon in 1902. *In*

Herdman, W. A. ed. Rept. Pearl Oyster Fisheries of the Gulf of Manaar. Part 1, p 169-176, 1 pl.

SHÔJI, K., 1938, A new commensal bivalve attached to a burrowing shrimp. Venus, 8: 119-128, pls. 3-4.

SMITH, A. G. and M. GORDON, 1948, The marine mollusks and brachiopods of Monterey Bay, California, and vicinity. Proc. Calif. Acad. Sci., ser. 4, 26: 147-245, pls. 3-4, 4 figs.

SMITH, E. A., 1877, Mollusca. Transit of Venus Expedition, 1874-1875. Phil. Trans. Roy. Soc. London, 168: 167-192, pl. 9.

SOOT-RYEN, T., 1959, Reports of the Lund University Chile Expedition 1948-59. Pelecypoda. Lunds Universitets Årsskrift, 55: 1-86, 4 pls.

SPÄRCK, R., 1931, *Cycladoconcha amboinensis* n. gen. n. sp., a commensalistic lamellibranch. Vidensk. Medd. Dansk Naturh. Foren., 91: 227-239, pl. 2.

STIMPSON, W., 1855, On some remarkable marine invertebrates inhabiting the shores of South Carolina. Proc. Boston Soc. nat. Hist., 5: 110-117.

________, 1857, On the Crustacea and Echinodermata of the Pacific shores of North America. Pt. I. Crustacea. J. Boston Soc. nat. Hist., 6: 444-531, pls. 18-23.

TATE, R., 1889, Description of some new species of marine Mollusca from South Australia and Victoria. Trans. Proc. Rept. Roy. Soc. South Australia (Adelaide), 11: 60-66, pl. 11.

VAYSSIÈRE, A., 1920, Étude sur la faune marine de la côte occidentale du Golfe de Marseille. Ann. Mus. Hist. nat., Marseille (Zool.), 17: 93-110.

VERCO, J. C., 1913, Note on *Lasaea scalaris* Philippi. Trans. Roy. Soc. South Australia (Adelaide), 37: 448-449.

VOELTZKOW, A., 1890, *Entovalva mirabilis*, eine schmarotzende Muschel aus dem Darm einer Holothurie. Zool. Jahrb. (Abt. Syst. Geogr. Biol.), 5: 619-628, pl. 42.

WHITEAVES, J. F., 1880, On some marine invertebrates from the Queen Charlotte Islands. Rept. Progress Geol. Survey Canada, 1878-1879. 16 p., 2 text-figs.

WINCKWORTH, R., 1923, *Montacuta bidentata* (Montagu). J. Conchol., 17: 86.

________, 1924a, Specimens of molluscs and other animals associated with them found in a day's digging at Salcombe. Proc. malac. Soc. London, 16: 1.

________, 1924b, *Lepton squamosum* (Mtg.), J. Conchol., 17: 158.

________, 1930, Notes on nomenclature 5. Some new names for British marine bivalves. Proc. malac. Soc. London, 19: 14-15.

WOLFF, T., 1959, Epifauna on certain decapod Crustacea. Proc. Int. Congr. Zool., 15: 1060-1061.

WOODWARD, M. F., 1893, On the anatomy of *Ephippodonta macdougalli*. Proc. malac. Soc. London, 1: 20-26, pl. 2.

YAMAMOTO, T. and T. HABE, 1961, *Nipponomontacuta actinariophila* gen. et sp. nov., a new commensal bivalve of the sea anemone. Publ. Seto mar. biol. Lab., 9: 265-266, 2 text-figs.

Note added in press:

Two recently discovered cases of commensalism have been reported from New Zealand by Ponder (1965, The biology of the genus *Arthritica*. Trans. Roy. Soc. New Zealand, Zoology, 6(8): 75-86). *Arthritica crassiformis* Powell lives attached to the external surface of the rock-boring pholad bivalve, *Anchomasa similis* (Gray), and a closely related species, *Arthritica hulmei* Ponder lives attached by its byssus to the inner surface of the elytra of the annelid sea mouse, *Aphrodita australis* Baird.

## RESUMEN

## BIVALVOS ERYNACEOS SIMBIOTICOS

Este trabajo sumariza la ocurrencia de comportamiento simbiótico entre representantes de los eulamelibranquios de la superfamilia Erycinacea. Casos individuales de comensalismo, mutualismo, o hasta ectoparasitismo y también aparente endoparasitismo, se presentan documentados. Los moluscos se discuten en relación a sus huéspedes con breves anotaciones concernientes a la causa general de esas asociaciones.

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# CONVERGENCE OF AN ACENTRIC SCULPTURAL TRAIT IN THE TELLINACEA.

Kenneth J. Boss, Bureau of Commercial Fisheries Ichthyological Laboratory, U. S. Fish and Wildlife Service, Washington, D.C.

## (Abstract)

**The occurrence of a peculiar kind of external superficial sculpture, herein termed scissulate, has been documented in several families of the Tellinacea, including the Donacidae, Gariidae, Semelidae, and Tellinidae. The species of at least 10 phyletically separate and distinct subgenera or genera exhibit this unique differential sculpture.**

**The most notable interfamilial convergence is that found between the semelid *Iacra* and the tellinid *Strigilla*. In species of these genera, not only is the scissulate sculpture similar, but the shape of the shell and the configuration of the pallial musculature are very much alike. Only the distinctive internal resilium of *Iacra* serves to differentiate its representative species from those of *Strigilla*.**

**Within the family Tellinidae, acentric sculpture occurs in no less than six independent generic or subgeneric lineages. The macomoids, *Scissulina*, *Temnoconcha*, *Jactellina*, and *Loxoglypta*, and the tellinoids, *Scissula*, *Strigilla*, and *Fabulina* have representative species with the distinctive trait.**

**To explain this remarkable incidence of convergence, the natural habits of members of the Tellinacea are reviewed. It is concluded that as infaunal members of the benthos, the Tellinacea are specialized deposit feeders which normally assume a horizontal position in sandy substrates. In most species, particularly in the family Tellinidae, there is an adaptive posterior flexure of the shell to the right side of the animal which is directed toward the surface of the substrate and from which the incurrent siphon emerges to draw in detritus. Further, in two independent subgenera of separate subfamilies, the widely distributed Indo-Pacific macomoid, *Macoma* (*Scissulina*) *dispar* (Conrad) and the European tellinoid, *Tellina* (*Fabulina*) *fabula***

Gmelin, only the right valve possesses the peculiar acentric sculpture. Since the structure of the acentric sculptural pattern is such as to offer a resistance to posteriorly directed movements by interlocking with the sand grains of the substrate, it is postulated that the scissulations are of value in the maintenance of the animal's position in the substrate when the siphons are being withdrawn. On the other hand, anteriorly directed movement, such as that generated by the extension of the foot and the coordinated contraction of the pedal musculature, is not diminished by the presence of the peculiar sculpture.

Since the acentric trait did not appear until relatively recently in the fossil record, it is most probable that the species of a number of different lineages within the superfamily have adapted to this peculiar form of sculpture which may aid the animal in its subsurface locomotion and its position in the substrate.

(The author wishes to thank Mr. Kjell Sandved who photographed some of the specimens used to illustrate this talk.)

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# THE FAMILY PANDORIDAE IN THE WESTERN ATLANTIC[1]

BY

KENNETH J. BOSS[2] AND ARTHUR S. MERRILL[3]

The family Pandoridae, as represented by its single nominate genus, is cosmopolitan in distribution with a concentration of species in the cooler waters of the northern hemisphere. A number of species are boreal while a single one is circumpolar. The coasts of eastern Asia, western North America and eastern North America constitute the areas in which *Pandora* is most highly differentiated. Tropical and subtropical waters do not appear to suit most members of the genus and the group is therefore poorly represented in the faunas of Africa, South America and the Indo-Pacific.

Within species of the northern hemisphere, allopatric patterns of geographic speciation are evident, and from the known embryological evidence, localized populations seem to be maintained by the short-lived pelagic stage. One phenomenon resulting from geographic isolation and subsequent evolutionary divergence is the existence of species pairs. In this case the new and distinct species, having been derived from the same ancestral stem, possess many morphological traits in common. Barriers to the genetic introgression of such populations may be either intrinsic or extrinsic, and in the present state of malacological knowledge, the extrinsic mechanisms are better known and more easily deduced. The classic example includes the numerous paired species found separated by the Isthmus of Panama.

In *Pandora*, the fauna of the Western Atlantic is largely represented by analogous elements in the Eastern Pacific. Such a distinctive barrier as an isthmus need not always be evident. The Japanese species *wardiana* Adams is analogous to the Pacific North American *grandis* Dall. Both species are very similar morphologically but *wardiana* is distinguished by its unusually great size. Intraoceanic speciation in the littoral fauna may also be detected by similar allopatric patterns. In the Western Atlantic, *gouldiana* and *trilineata* exemplify this phenomenon and are analogous species. Gardner (1943) has noted that this specific distinction may be traced to the Miocene.

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[1] Published with the aid of a Milton Grant.

[2] Ichthyological Laboratory
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Department of Interior
Washington, D.C.

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United States Fish and Wildlife Service
Department of Interior
Oxford, Maryland

Contrary to Dall (1903) and Grant and Gale (1931), the fossil history of *Pandora* begins in the Tertiary not in the Cretaceous (Zittel, 1900). Stoliczka (1871) has confirmed this by asserting that no recognizable *Pandora* occur in Mesozoic deposits. In Europe, the genus has been found as early as the Eocene of the Paris Basin (Deshayes, 1860; Cossmann, 1886), and the fossil species *primaeva* Deshayes of these sediments is not unlike modern *glacialis*. The genus does not appear until the Miocene in North America; there do not seem to be any available Eocene records. The modern elements of the Western Atlantic fauna may be traced directly to the Miocene where numerous species had already developed.

## ANATOMICAL NOTES

In *Pandora*, the thin transparent mantle is thickened ventrally and its lobes are united along its entire length except for the pedal and siphonal gapes. Along the edge of the mantle, the outer, middle and inner lobes may be most easily discerned at the pedal gape which extends from the anterior adductor muscle ventrally to a point just behind the base of the foot (pl. 115, 15). At this point the inner longitudinal muscular lobes of the mantle edge fuse; the fusion is complete to the incurrent siphon and not only a cuticular junction (Allen, 1954). In *Pandora gouldiana*, the incurrent siphon (pl. 115, 10) possesses two rows of papillae, the inner row generally with about 15 18, the outer row with about 18–20. The excurrent siphon (pl. 115, 9) has only a single row of papillae, numbering about 20 in *gouldiana* (Perkins, 1869; Morse, 1919). The siphons are

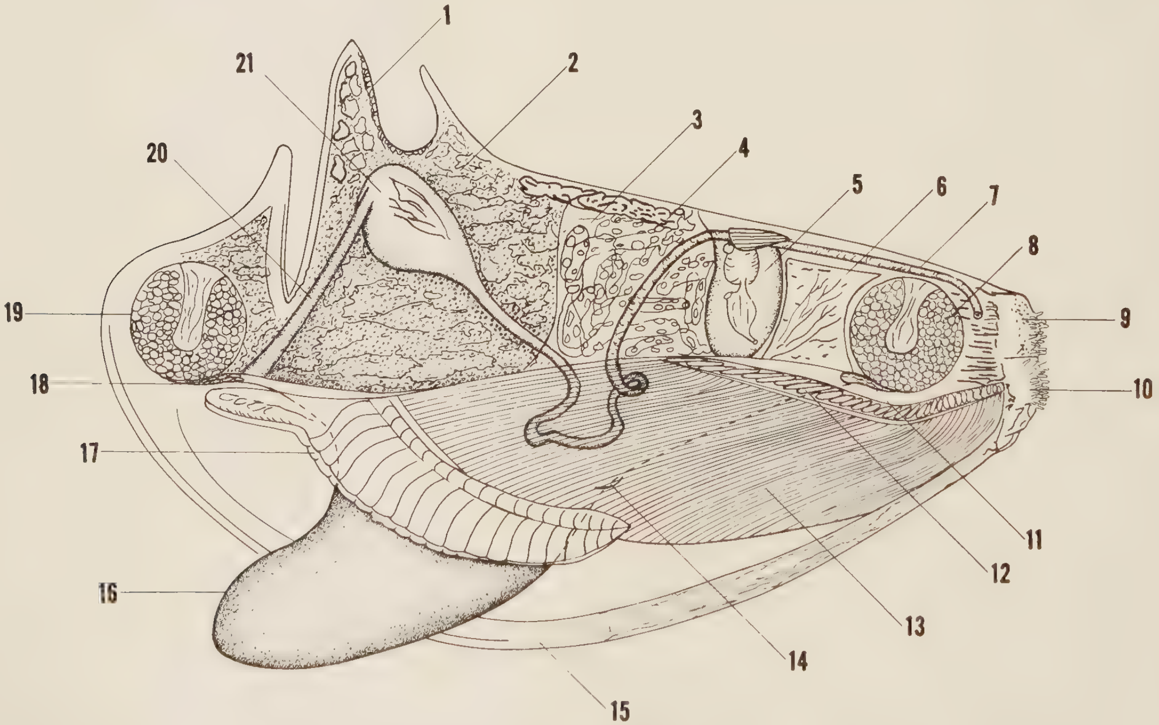

Plate 115. Diagram of the gross anatomy of *Pandora gouldiana* Dall, left valve and mantle removed. 1. Specialized cells to secrete resilium and lithodesma. 2. Digestive diverticula. 3. Ovary. 4. Pericardial (Keber's) gland. 5. Heart. 6. Kidney. 7. Rectum. 8. Posterior adductor muscle with quick and catch muscle fibers. 9. Excurrent siphon with papillae. 10. Incurrent siphon with papillae. 11. Posterior pedal retractor. 12. Outer demibranch. 13. Inner demibranch. 14. Byssal gland and groove. 15. End of mantle union and beginning of pedal gape. 16. Foot. 17. Labial palps. 18. Anterior pedal retractor. 19. Anterior adductor muscle with quick and catch muscle fibers. 20. Esophagus. 21. Stomach.

short, united at their bases but separated by an internal intersiphonal septum. In *gouldiana*, the siphons are light brown in color, mottled with black dots. The muscular lobes of the mantle are thickened in this area to form the siphonal retractor muscles; nevertheless, the siphons are not capable of great extension and the animal in its burrowing habit is more or less limited to the epifaunal regions of the substrate.

The thickened muscle lobes of the mantle attach irregularly to the shell to form a discontinuous pallial line (pls. 117 and 118, 5). The anterior and posterior adductor muscles (pl. 115, 8 and 19) are subequal in size and are differentiated into "catch" and "quick" fibers. The anterior pedal retractor (pl. 115, 18) has its origin along the ventral surface of the anterior adductor muscle and inserts antero-dorsally in the foot. It is more extensive and better developed than the posterior pedal retractor (pl. 115, 11) which is small, thin and somewhat tendon-like. The latter muscle inserts into the foot postero-dorsally and has its origin at the base of the posterior adductor muscle. Both pedal retractors are unusual in that their origins are along the ventral border of the adductor muscles.

The mantle is completely united dorsally and there is a specialized area of cells beneath the umbo which function in the secretion of the resilium and the lithodesma (pl. 115, 1; and pls. 117–118, 8 and 9).

The laterally compressed foot (pl. 115, 16) is large, well developed and capable of considerable extension through the antero-ventral pedal gape. A byssal gland and groove (pl. 115, 14) are present but no byssus is developed in the adult stage although early post-larval *Pandora* may utilize byssal strands for attachment to the substrate (Allen, 1961).

As is characteristic of members of the Anatinacea, the gills of *Pandora* are separated into dorsally upturned outer and ventral inner demibranchs (Deshayes, 1848; Menegaux, 1890). The outer demibranch (pl. 115, 12) is small and very much reduced, consisting of only a single direct lamella (Pelseneer, 1911). The inner demibranch (pl. 115, 13), consisting of both internal and external lamellae, extends posteriorly nearly to the opening of the incurrent siphon where they are pendantly free and not attached to the siphonal septum as in *Anatina* (Burne, 1920). Just ventral and posterior to the foot at the nominal origin of the posterior pedal retractor muscle, the inner demibranch of the right and left sides unite. The remainder of the anterior portion of the demibranch is attached along its proximal margin to the body. The lamellae of *Pandora inaequivalvis* Linnaeus are plicate and heterorhabdic with a specific number of filaments per plica (Ridewood, 1903). Atkins (1937) has described the ciliary currents, and Allen (1954) has figured the sorting mechanisms of the gill ciliation. The paired and bilobed labial palps (pl. 115, 17) are plicate and contiguous with the inner demibranch.

The mouth is situated at the anterior margin of the labial palps. In *Pandora gouldiana*, a relatively long esophagus (pl. 115, 20) leads to the stomach (pl. 115, 21) which possesses a developed gastric shield and crystalline style. Allen (1954) and Purchon (1958) have described in detail the structure and function of the stomach of *Pandora inaequivalvis*. A large diffuse digestive diverticulum surrounds the stomach and connects with it by numerous ducts. The style-sac is combined with the midgut which extends postero-ventrally from the stomach, convolutes in the testicular tissue of the foot and arises abruptly to pass through the tubulous ovary and then through the pericardial wall to form the rectum. Continuing posteriorly out of the pericardium the rectum passes over the dorsum of the posterior adductor muscle and terminates with the anus in the excurrent siphonal cavity.

The structure of the nervous system of *Pandora* has been discussed by Duvernoy (1854). It is sufficient to mention that the cerebropleural ganglia are near the ventral surface of the anterior adductor muscle and are connected by a commissure. Long cerebro-visceral connectives extend posteriorly to the visceral ganglia at the base of the posterior adductor muscle, and separate cerebro-pedal connectives join the cerebropleural ganglia to the pedal ganglia. According to Pelseneer (1911), there are paired otoliths associated with the pedal ganglia.

The cardiac system of *Pandora* (see pl. 116) includes'a large pericardium within which the paired auricles and ventricles are located and through which the rectum passes. The auricles attach to the pericardial wall near the kidneys and lead dorsally to the paired ventricles which lie below the alimentary canal. The ventricles then unite to form a common bulbus arteriosus which envelopes a portion of the rectum and which gives rise to the anterior and posterior aortae. Both the ventricle and auricle possess spheroidal structures the function of which is unknown. Dorso-lateral to the pericardium are the paired Keber's organs or pericardial glands.

As noted by Lacaze-Duthiers (1854), *Pandora* is monoecious with both male and female gonads occurring in a single individual. It appears that this hermaphroditic condition is typical of the Anatinacea. Arvy and Gaillard (1956) have noted that in *Pandora inaequivalvis* a parasitic cercarean, *Cercaria melanocystea*, destroys the gonad tissue, and replaces it with dark colored sporocysts. The nephridial system of *Pandora glacialis* has been considered by Odhner (1912), and pl. 117 illustrates the general structure of the reproductive and nephridial systems in *Pandora*. The ovary is more or less dorsal, tubular and superficial, occupying the central portion of the visceral mass. The testis is diffuse and consists of irregular glandular tissue buried deeply about the convolutions of the in-

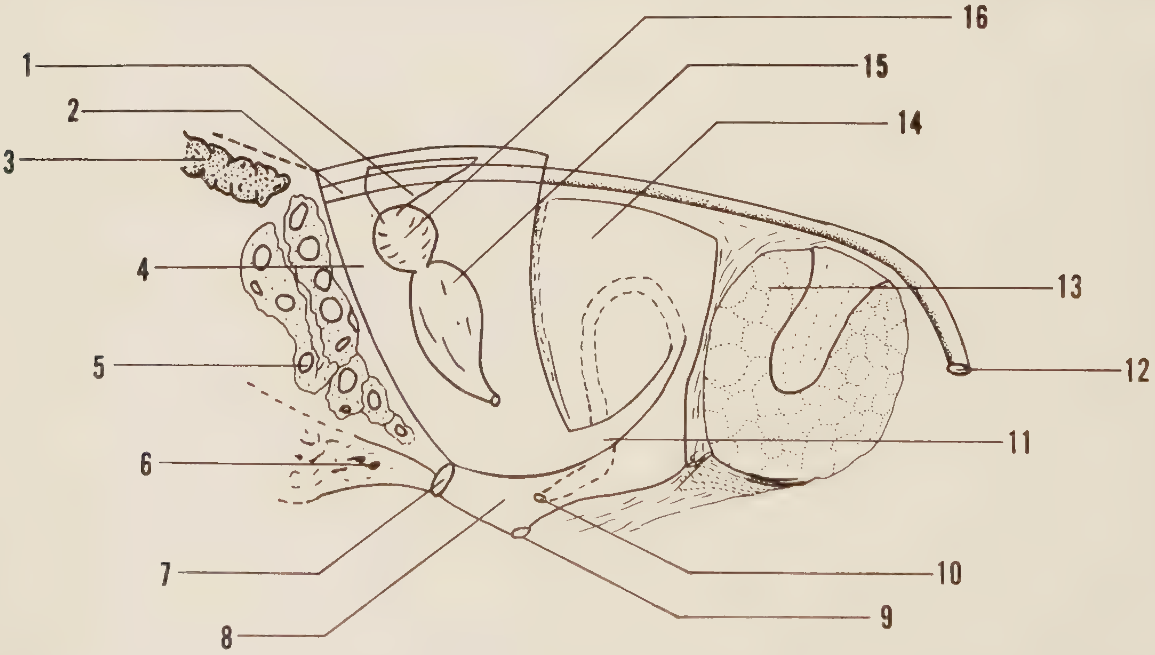

Plate 116. Diagram of the urogenital system of *Pandora*. 1. Bulbus arteriosus. 2. Rectum. 3. Pericardial gland (Keber's organ). 4. Pericardium. 5. Ovary. 6. Testis. 7. Common genital pore. 8. Urogenital canal. 9. Urogenital pore or orifice. 10. Nephroproct. 11. Reno-pericardial canal (Wimpertrichter). 12. Anus. 13. Posterior adductor muscle. 14. Kidney. 15. Auricle. 16. Ventricle.

testine in the dorsal mass of the foot. The testis and ovary open via a common genital pore into the urogenital canal. The kidney is located between the pericardium and the posterior adductor muscle. A ciliated reno-pericardial funnel or Wimpertrichter connects the cavity of the pericardium with the kidney. Thence the kidney leads via a renal orifice or nephroproct into the urogenital canal. Excretory wastes and reproductive products are thereby expelled into the suprabranchial chamber via a common urogenital orifice or pore.

Eggs in the ovary are already encapsulated and Pelseneer (1911) detected zygotes in early developmental stages within the gills and pallial cavity of *Pandora elongata* Carpenter. Burne (1920) reported eggs in the suprabranchial chamber of *Anatina*. Internal incubation appears to occur with some frequency within the Anatinacea.

The developmental biology of *Pandora inaequivalvis* has been discussed by Allen (1961). In that species, the eggs are quite large (105–125 μ in diameter) with considerable food reserves and similar lecithotrophic conditions also are found within *P. glacialis* Thorson (1936); Ockelmann (1958) and *P. gouldiana* (Perkins, 1869). Development appears to be rapid with metamorphosis occurring in less than four days. The larvae are generally released from the encapsulated eggs within 22 hours after fertilization and the veliger is short-lived, spending less than 24 hours in the plankton; dispersal, therefore, is somewhat minimized. In the settling stage of the dissoconch, attachment to the substrate is implemented by means of a byssus, and complete metamorphosis including the development of the labial palps, gills and foot is then completed. Allen's observations (1961) were experimentally derived, but they do not preclude the possible incubation of young as indicated by Pelseneer (1911). The time of spawning appears to vary from species to species. In *gouldiana*, it takes place in late spring or early summer, while in *glacialis* it occurs in late August (Ockelmann, 1958). We have seen eggs of *gouldiana* extended in mucus strands from the outer perimeter of the mantle. Presumably these mucus strands cling to the substrate until the eggs develop to a free-swimming stage. The eggs, obtained from specimens in Woods Hole, Massachusetts, measured between 130–140 μ.

## SHELL MORPHOLOGY

The shell structure of *Pandora* has been discussed by Carpenter (1848). He described the shell of *Pandora inaequivalvis* as consisting of an internal nacreous and laminate layer and an external crystalline, prismatic layer. Between these layers is a so-called membranous partition. An organic periostracum covers the external portions of the shell and when this is worn away the underlying prismatic layer may be abraded revealing the internal aragonitic nacre. The abrasion of the prismatic layer appears to be common in such species as *Pandora gouldiana* and causes the external aspect of the shell to become a dull powdery white.

The ligament in *Pandora* consists of a number of portions. Posterior to the umbo and connecting the opposing valves, there is a thin ligamental sheath formed by a thickened periostracal covering. Along the anterior dorsal margin, another somewhat stronger sheath of ligamental tissue joins the valves; the attachment of this ligamental tissue is particularly evident in the left valve of *Pandorella* where a slight concavity is present along the anterior dorsal margin near the anterior cardinal tooth (pl. 119, 3). Internally a strong resilium is developed which consists of compressed layers of ligamental material.

In some subgenera, notably *Pandorella* and *Clidiophora*, a calcified supportive lithodesma subtending the resilium is developed.

The configuration of the dentition is somewhat complex in *Pandora*. It appears that quite recently some measure of morphological stability has been reached in the evolution of these structures. Dall (1903) recounted the numerous irregularities and the lack of stability in the fossil representatives of *Pandora* in the Miocene of North America. Even in the recent species, particularly in such species as *Pandora gouldiana* Dall, variation of dental configuration is considerable. One of the simplest dental patterns is encountered in *Pandora inaequivalvis* Linnaeus, which has a well developed central pedunculate cardinal tooth in the right valve and poorly developed posterior and central teeth in the left.

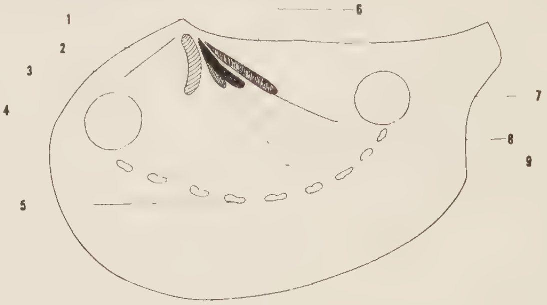

Plate 117. Diagram of the right valve of *Pandora gouldiana* Dall. 1. Umbo. 2. Anterior cardinal tooth. 3. Central pedunculate cardinal tooth. 4. Anterior adductor muscle scar. 5. Pallial muscle scar. 6. Posterior cardinal tooth. 7. Posterior adductor muscle scar. 8. Resilium. 9. Lithodesma.

For the purposes of uniformity and clarity, the following descriptive system will be utilized in discussion of the morphology of each species. The structural configuration upon which the discussion is based is taken from *Pandora gouldiana*, where a full complement of representative dental structures is present (pls. 117 and 118).

The dorsal internal hinge of the left valve possesses a number of unconformities—thickenings, protuberances and concavities. The anteriormost of these is called the anterior cardinal tooth. It may take the form of an elongate conspicuous internal ridge which is dorso-ventrally aligned (e.g., *gouldiana*, pls. 117 and 118, 2) or it may coalesce with the anterior dorsal margin to form a thickened structure along the hinge line and be aligned in an anterior-posterior direction (e.g., *glacialis*, pl. 119, 2). This tooth or its representative in a fusion with the hinge line is always evident to some degree. Its particular type of formation is a clue to subgeneric affinities in that *Clidiophora* possesses a

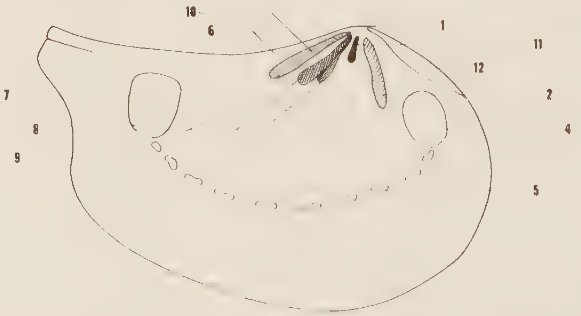

Plate 118. Diagram of the left valve of *Pandora gouldiana* Dall. 1. Umbo. 2. Anterior cardinal tooth. 4. Anterior adductor muscle scar. 5. Pallial muscle scar. 6. Posterior cardinal tooth. 7. Posterior adductor muscle scar. 8. Resilium. 9. Lithodesma. 10. Posterior fossa for the intrusion of the posterior cardinal tooth of the opposite valve. 11. Median cardinal tooth. 12. Anterior dorsal margin and ligamental concavity.

distinct anterior cardinal tooth parallel to the dorso-ventral axis of the shell, and *Pandorella* possesses a less distinct tooth, usually somewhat adpressed to the anterior dorsal margin and arranged in an anterior-posterior plane. The anterior terminus of this tooth presents a relationship to the anterior adductor muscle scar. In *Clidiophora*, the scar may or may not rest wholly beneath the terminus while in *Pandorella* the anterior adductor muscle scar is generally beneath the terminus or ventral border of the tooth.

Along the dorsal margin beneath the umbos is a deep cavity immediately behind the proximal terminus of the anterior cardinal tooth. The cavity or fossa receives the central, pedunculate cardinal tooth (pl. 117, 3) of the right valve when the valves are interlocked. A thin, raised central tooth (pl. 118, 11) separates the cavity for the pedunculate tooth from the resilial complex. The resilium (pl. 117, 8) rests upon an excavated surface, the posterior portions of which are slightly thickened and elevated to form the boundary of the posterior fossa or cavity (pl. 118, 10) which is the interlocking fixture for the posterior tooth of the right valve. Along the posterior dorsal margin of the valve, this fossa has a thickened ridge nominally referred to as the posterior cardinal tooth (pl. 118, 6), but in reality this is not a strong or well developed structure in *gouldiana*. Subtending the resilium is the calcareous lithodesma. In *Pandora claviculata*, the type of *Clidiophora*, there is a particularly well developed and elongate posterior lateral tooth which extends parallel to the posterior dorsal margin of the valve. In the subgenus *Foveadens*, as represented by *Pandora panamensis* Dall from the Eastern Pacific, there is a connective shelf which unites the long posterior lateral cardinal tooth with the posterior dorsal margin to form a hollow structure. While in other groups, notably the South Pacific *Coelodon*,

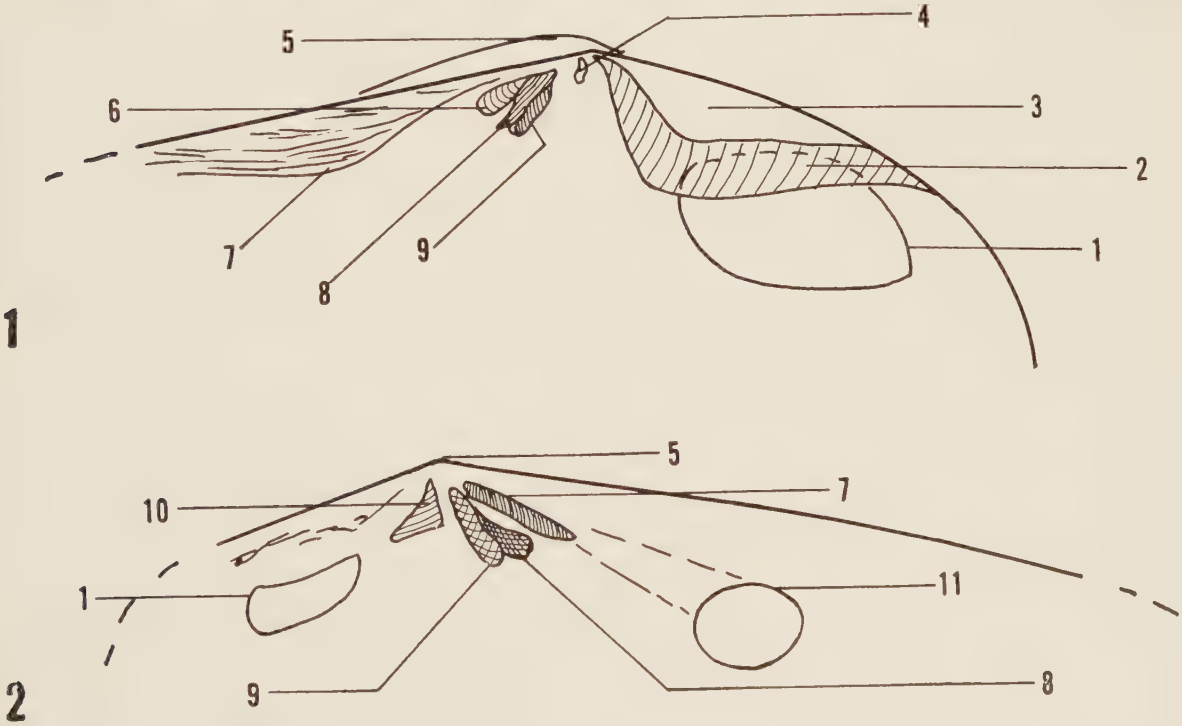

Plate 119. Diagrammatic enlargement of the hinge of *Pandora glacialis* Leach. Fig. 1. Internal view of the left valve. Fig. 2. Internal view of the right valve. 1. Anterior adductor muscle scar. 2. Anterior cardinal tooth. 3. Anterior dorsal margin and ligamental area. 4. Median cardinal tooth. 5. Umbo. 6. Posterior fossa for the intrusion of the posterior cardinal tooth of the right valve. 7. Posterior cardinal tooth. 8. Resilium. 9. Lithodesma. 10. Central pedunculate cardinal tooth. 11. Posterior adductor muscle scar.

as represented by *Pandora ceylanica* Sowerby, this tent-like connective structure occurs between the anterior and medial cardinal teeth.

The dentition of the right valve is characterized by an anterior cardinal tooth (pl. 117, 2) which radiates from the umbo to the dorsal margin of the anterior adductor muscle scar and which is defined by a radial fossa or sulcus which parallels it. In *Pandorella* and *Pandora* s.s. this cardinal tooth is so obscure that it usually is described as being absent, whereas in *Clidiophora* it is more highly developed and distinct and in *Coelodon* the tooth is strong and elevated. Medially there is a strong and central pedunculate cardinal tooth (pl. 117, 3) which is semilunate, subtrigonal, or diamond-shaped in cross section. This tooth appears to be developed in all species. Posterior to the pedunculate cardinal tooth is the resilium (pl. 117, 8) which rests on the excavated anterior under surface of the posterior cardinal tooth (pl. 117, 6). The calcareous lithodesma is attached to the ventral surface of the resilium. The posterior cardinal tooth is variously developed, ranging from a short stubby excrescence as seen in *P. inflata*, new name (=*brevis* Verrill & Bush) to the elongate thickened and strong structure in *P. gouldiana*. In *P. inaequivalvis*, the posterior tooth is obsolete and regarded as completely absent. It is not unusual for a thickened internal riblet to extend from the distal terminus of the posterior cardinal tooth toward the posterior adductor muscle scar.

The dentition is not as well developed in all species as it is in *gouldiana*. For example, in *inaequivalvis*, the left anterior cardinal tooth is somewhat hollowed beneath and buttressed with a ventral flange. The posterior fossa is not developed and no definite posterior tooth may be identified. In the right valve, the anterior cardinal tooth is obsolete, being represented by a feeble ridge, and no vestige of a posterior tooth is evident; only the central pedunculate cardinal tooth is strong and conspicuous. A lithodesma is lacking in *inaequivalvis* and in combination with the reduced dentition, these characters define the nominate subgenus.

### ABBREVIATIONS

| | |
|---|---|
| ANSP | Academy of Natural Sciences of Philadelphia |
| BCF | Bureau of Commercial Fisheries, Woods Hole, Massachusetts |
| BMNH | British Museum (Natural History), London |
| MCZ | Museum of Comparative Zoology |
| USNM | United States National Museum |

The aforementioned abbreviations are used predominantly in the section under each species entitled "specimens examined." We have made a special note of those stations where living specimens were collected by the insertion of "(live)" following the station data. Where no comment is made, the specimens collected were dead.

## SYSTEMATIC TREATMENT

### Superfamily ANATINACEA

### Family PANDORIDAE *Gray* 1847

*Description.* Shell of small to moderate size, not exceeding 60 mm. in length, crescent-shaped, more or less compressed, inequilateral with the anterior portion short and the posterior long and often rostrate, inequivalve with the left valve usually the more convex and larger and the right valve flattened or somewhat concave. Umbo generally elevated, pointed and often corroded. Hinge complex, with subexternal ligamental portions and an internal resilium, which is sometimes supported by a calcareous lithodesma. Hinge dentition variable but generally the right valve possesses a large pedunculate, central cardinal tooth while the left valve possesses anterior and/or posterior cardinal teeth. Shell generally whitish; external prismatic layer rather easily corroded; internal layer nacreous.

## Pandora *Bruguière* 1797

*Pandora* Bruguière 1797, Encyclopédie Méthodique, Vers Testacés **2**: pl. 250, figs. 1a–c; Lamarck 1799, Mem. Soc. Hist. Nat. Paris, an. vii, p. 88 (type species by subsequent monotypy, Lamarck 1799, *Tellina inaequivalvis* (Linnaeus) 1758), *non* Mühlfeld 1811 (Mollusca), *nec* Eschscholtz 1829 (Ctenophora), *nec* Haliday 1833 (Diptera), *nec* Chevrolat 1834 (Coleoptera), *nec* Westwood 1848 (Lepidoptera), *nec* Koch 1850 (Arachnida), *nec* Sars 1895 (Crustacea).

*Calopodium* Röding 1798, Museum Boltenianum, 1st Ed., p. 166; 1819, *Ibid.*, 2nd Ed., p. 116 (type species by monotypy, *Calopodium albidum* Röding [=*Tellina inaequivalvis* (Linnaeus) 1758]).

*Trutina* Brown 1827, Illustrations of the Conchology of Great Britain and Ireland, 1st Ed., pl. 13, fig. 5; 1844; *Ibid.*, 2nd Ed., p. 104, pl. 47, figs. 5, 12 and 13 (type species by monotypy, *Trutina solenoidea* Brown [=*Solen pinna* Montagu 1803 (=*Tellina inaequivalvis* (Linnaeus) 1758)]).

*Pandorina* Scacchi 1836, Catalogus conchyliorum regni neapolitani, p. 6, *non* Scacchi 1833 (Mollusca), *nec* Bory de St. Vincent 1827 (Protozoa).

The generic name *Pandora* possesses a complex nomenclatorial history and it is hoped that the present treatment may settle some of the discrepancies of the past as well as rule out the possible usage of any junior synonyms. The name originated with Hwass and its introduction dates from Chemnitz (1795) who remarked:

> Der Herr Justissrath Hwass hat aus solchen Tellinen, die oben einen flachen Deckel und unten eine tiefe Unterschale haben, wie *Tellina inaequivalvis*, *crystallina* und andere, ein neu Geschlecht errichtet und es *Pandora* genannt.

Some controversy concerning the appropriate generic name was interjected into the the literature by Prashad (1932) and Winckworth (1934). In 1944, the International Commission of Zoological Nomenclature published Opinion 184 which had the effect of sanctioning the generic names of Chemnitz which occurred in the nonbinomial volumes of the Conchylien-Cabinet. Various authors thereby quoted "*Pandora* Hwass [in] Chemnitz" or merely "*Pandora* Chemnitz" (Hertlein and Strong, 1946; Keen, 1958; Palmer, 1958; Olsson, 1961). Opinion 184 was reversed with the decision to place the first eleven volumes of the first edition of the Neues Systematisches Conchylien-Cabinet of Martini-Chemnitz on the official index of rejected literature. This action rendered *Pandora* Chemnitz unavailable.

Prashad (1932) recognized that the name *Calopodium* Röding 1798 was introduced before Lamarck's usage of *Pandora*. Numerous workers were aware that Bruguière had included *Pandora* without a trivial name in a plate caption in the Encyclopédie Méthodique. For plate 250 of volume 2 of the plates, Sherborn and Woodward (1906) have established the correct date as 1797. Stewart (1930) employed Bruguière's name and, notwithstanding the evidence marshalled by Dodge (1947), the generic name *Pandora* Bruguière 1797 is valid and available according to the International Code of Zoological Nomenclature (1961) (15th Congress), Art. 11 (c) (i) and Art. 16 (a) (vii).[1]

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[1] Winckworth (1934) would no doubt have given the same interpretation but was held to Opinion 1 (1907) which eliminates names based on plate captions.

The questions concerning type species and type designations for the genus have been variously interpreted (Palmer, 1958). There are actually numerous subsequent and different type designations for the genus (Schmidt, 1818; Children, 1823; Gray, 1847; Stoliczka, 1871; Kobelt, 1878; Dall, 1903). Lamarck (1799) was the first to use *Pandora* with a specific epithet and an interpretation of the Code shows that *Tellina inaequivalvis* Linnaeus becomes the type species by subsequent monotypy [Art. 68 (a) (ii) (2)].

Röding (1798) introduced *Calopodium* with the single species *albidum*, under which *Tellina inaequivalvis* Linnaeus was given as the only reference. Therefore, *Calopodium albidum* is a junior synonym of *Tellina inaequivalvis* and the generic name *Calopodium* is absolutely synonymous with *Pandora.*

## Subgenus **Clidiophora** *Carpenter*

*Clidiophora* Carpenter 1864, Proc. Zool. Soc. London, p. 576 (type species, by original designation, *Clidiophora claviculata* Carpenter 1855 [=*Pandora arcuata* Sowerby 1830]).

*Clidiphora* 'Carpenter' Johnson 1934, Proc. Boston Soc. Nat. Hist. **40** (1): 31, error for *Clidiophora* Carpenter.

According to Dall (1903), *Clidiophora* is characterized by three teeth in the left valve, the posterior of which is much elongated and by three teeth in the right valve, the anterior of which is weak. A lithodesma, subtending the internal resilium, is present.

*Clidiophora* is represented by three species in the Western Atlantic. The type of the subgenus is found in the Eastern Pacific and possesses an unusually elongate posterior cardinal tooth in the left valve. None of the Western Atlantic species possesses such a highly developed right posterior cardinal tooth. The diagnostic traits which separate this subgenus from *Pandorella* include the nature of the left and right anterior cardinal teeth. In the right valve, the anterior cardinal tooth is weak and obsolete, but nevertheless a definitive structure may be discerned extending from the umbonal area to the dorsal margin of the anterior adductor muscle scar. The right posterior cardinal tooth is somewhat diagnostic since it is more elongate and stronger than the homologous structure in *Pandorella.* Most important, and perhaps the most easily detected, diagnostic trait is the left anterior cardinal tooth which extends more or less perpendicularly to the antero-posterior axis of the shell (that is, it is more or less parallel to the dorso-ventral axis). In *Pandorella* this structure is not aligned in a dorso-ventral direction. In *Pandora s.s.* the tooth is coalesced with the anterior dorsal margin and a lithodesma is absent (see pls. 118 and 119, 1).

## **Pandora (Clidiophora) gouldiana** *Dall*

Plate 120, figs. 3–4; Plate 121, fig. 4; Plate 122, figs. 5–6

*Pandora trilineata* 'Say' Conrad 1831, Amer. Marine Conch., p. 49, pl. 11, figs. 1–2; Russell 1839, Jour. Essex County Nat. Hist. Soc. **1**(2): 54; Gould 1841, Invert. Mass., 1st Ed., p. 44; DeKay 1843, Nat. Hist. N.Y. **5**: 239, pl. 33, figs. 310 a–b; Mighels 1843, Boston Jour. Nat. Hist. **4**: 314; Stimpson 1851, Shells New England, p. 23; Binney 1870 [in] Gould, Invert. Mass., 2nd Ed., p. 62, fig. 379; Perkins 1869, Proc. Boston Soc. Nat. Hist. **13**: 143; Tryon 1874, Amer. Marine Conch., p. 136, pl. 18, figs. 305–7; Apgar 1891, Jour. New Jersey Nat. Hist. Soc. **2**(2): 108; Morse 1919, Proc. Boston Soc. Nat. Hist. **35**(5): 160–1, fig. 17, *non* Say 1822.

*Pandora* (*Clidiophora*) *gouldiana* Dall 1886, Bull. Mus. Comp. Zool. **12**: 312; 1889, Bull. 37, United States Nat. Mus., p. 68, pl. 59, fig. 14; 1902, Proc. United States Nat. Mus. **24**: 511, pl. 32, fig. 7 (type locality, Woods Hole, Mass.; holotype, USNM 95490).[1]

*Pandora* (*Clidiphora*) *gouldiana* Dall, Johnson 1934. Proc. Boston Soc. Nat. Hist. **40**(1): 31, error for *Clidiophora* Carpenter.

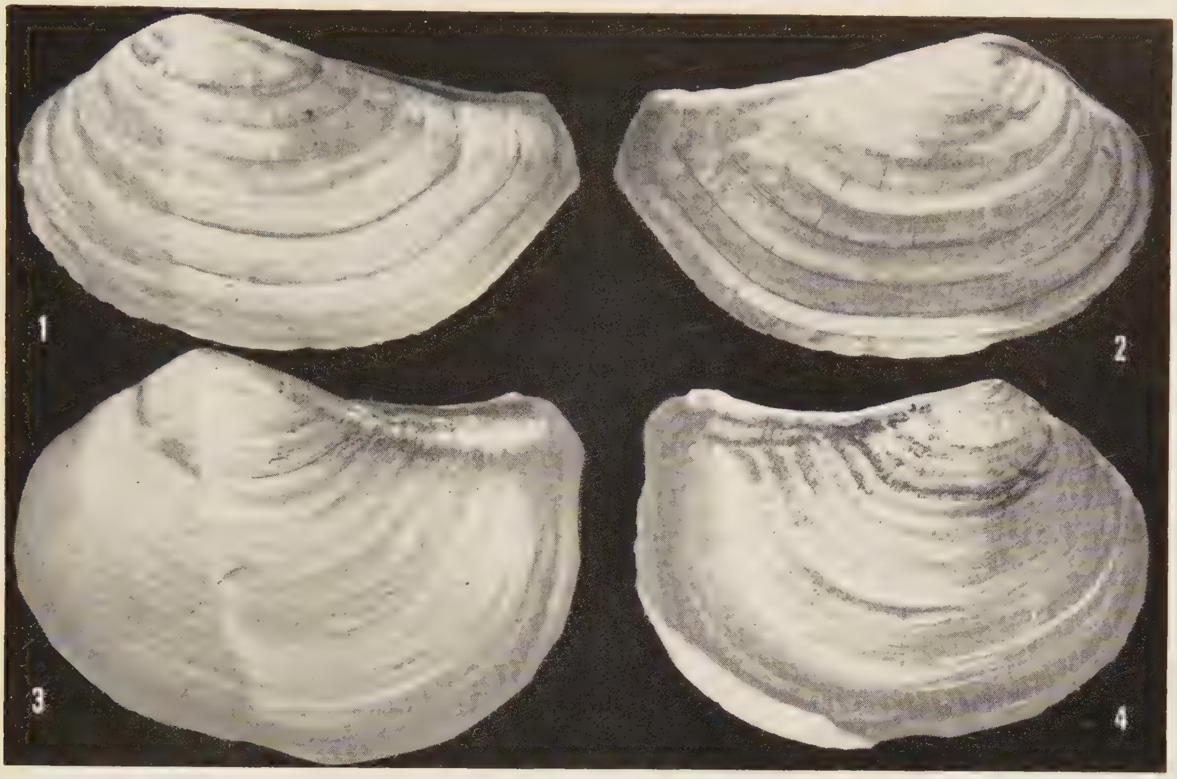

Plate 120. Figs. 1 and 2. *Clidiophora inornata* Verrill and Bush 1898 [=*Pandora* (*Clidiophora*) *inornata*]. USNM 49760, *Speedwell*, Station 327, off Cape Cod, south end of Stellwagen Bank, in 17 fathoms. Fig. 1. External view of the left valve of a syntype (4.7x). Fig. 2. External view of the right valve of a syntype (4.7x). Figs. 3 and 4. *Pandora* (*Clidiophora*) *gouldiana* Dall 1886. USNM 95490, Woods Hole, Massachusetts. Fig. 3. External view of the left valve of the holotype (2.6x). Fig. 4. External view of the right valve of the holotype (about 2.4x).

*Description.* Shell extending to 35 mm. in length (about 1½ inches) and to 27 mm. in height (about 1 inch), somewhat compressed, thin or subsolid to solid in large adults, inequilateral, inequivalve with the left valve of a weak convexity and with the right valve more or less flattened but often centrally a little convex and weakly swollen. Umbos in the anterior third of the shell, elevated, pointed and conspicuous. Anterior margin somewhat broadly rounded and distinctly separated from the ventral margin at the terminus of the anterior radial sulcus; ventral margin convex, rising behind and slightly indented beneath the rostrum; anterior dorsal margin straight to convex, smoothly confluent with the anterior margin in adults but generally well differentiated in youthful stages; posterior dorsal margin long, concave and rising posteriorly to form a rostrum; posterior margin very short and more or less oblique to the dorso-ventral axis of the shell. In the left valve, there is at least one strong posterior radial ridge extending from the umbo to the base of the posterior margin and usually another more dorsal ridge is found with a

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[1] Dall noted that what numerous New England authors had been calling *trilineata* Say was truly a species hitherto undescribed and that true *trilineata* Say was a form with a more southerly range. Dall very briefly described *gouldiana* in a footnote in the *Blake* report and then later figured it.

sulcus between the ridges; these ridges generally define the rostrum. An anterior radial sulcus extends in a nearly straight line, dorso-ventral fashion from the umbo to the place where the ventral margin and the anterior margin are confluent; this sulcus sharply delimits the two margins. In the right valve a weak posterior radial sulcus extends from the umbo to the base of the posterior margin just ventral to the posterior dorsal margin. Concentric sculpture evident on the left valve as irregular, coarse undulations. Radial lines may be evident on the right valve. Hinge generally stout, strong and well developed; resilium with a lithodesma. In the left valve, the anterior cardinal tooth dorsoventrally straight to arcuate, separate from the anterior dorsal margin; central tooth short, small and obsolete; resilium long, resting in a depression which is thickened along its sides; posterior cardinal tooth consists of a mere thickening of the hinge line. In the right valve, the posterior cardinal tooth is strong, acutely subtrigonal, and the resilium rests in a fossa along its anterior surface; central pedunculate tooth elongate to sublunate; anterior tooth more or less obsolete and weak, grooved behind and extending from the umbonal region directly to the dorsal boundary of the anterior adductor muscle scar. Muscle scars rounded and well impressed. Pallial sinus consisting of small individual scars extending between the anterior and posterior adductor muscle scars. Color white, powdery to shining externally, nacreous internally.

| length | height | width | |
|---|---|---|---|
| 28.5 mm. | 19.5 mm. | 4.0 mm. | Holotype of *gouldiana* Dall |
| 34.3 | 21.4 | 5.8 | Duxbury, Mass. |
| 32.6 | 22.0 | 7.0 | Harpswell Island, Maine |
| 32.3 | 26.1 | 6.6 | off Wellfleet, Massachusetts Bay |
| 29.0 | 18.4 | 5.2 | Winthrop, Mass. |
| 27.4 | 16.9 | 4.5 | Woods Hole, Mass. |
| 22.7 | 13.3 | 2.6 | " " " |
| 18.9 | 12.4 | 2.4 | off Block Island, Mass. |
| 15.3 | 8.5 | 2.0 | " " " " |
| 9.4 | 4.7 | 1.1 | Long Island, New York |

*Remarks. Pandora gouldiana* appears to be one of the most common *Pandora* of the Western Atlantic and it is often encountered as a conspicuous element in the littoral fauna of New England. It has been recorded in numerous faunal lists and some literature concerning its natural history is available. Early New England authors confused this northern species with the slender and elongate allopatric southern species *Pandora trilineata* Say. The latter is distinctly the closest ally of *gouldiana* and as Jacot (1921) and Richards (1936) have indicated, there is some doubt about the specific identity of each. The primary distinguishing trait which separates *gouldiana* from *trilineata* is in the proportion of the shell. The length-height ratio in *trilineata* is greater than it is in *gouldiana;* that is, *trilineata* is more elongate and narrow whereas *gouldiana* tends to be more quadriform or subrectangular. The posterior rostrum in *trilineata* is therefore more conspicuous and distinct while in *gouldiana* the rostrum is short, tending toward bluntness. The height of the valve just anterior to the beginning of the rostrum is greater in *gouldiana* and, in point of fact, the ventral margin tends to be convex and expanded in this region. On the contrary, *trilineata*, is narrowed posteriorly, the ventral margin rising more abruptly and the shell height contracted. It may be said that *gouldiana* is coarsely sculptured with undulations in the left valve and that the shell appears to be thicker and heavier than its southern counterpart which has been called the "elegant, slender'' species. *Pandora gouldiana* and *trilineata* appear to be allopatric but in contradiction to Dall (1903), *trilineata* does range north of Cape Hatteras and has been represented in numerous samples taken in Chesapeake Bay.

Another close relative of *gouldiana* is the sympatric species *inornata*, which lacks the definitive posterior radial ridges. A full account of the differences separating *gouldiana* and *inornata* is given under 'Remarks' in *inornata.*

The range of variation exhibited by *gouldiana* is particularly important in regard to dental configuration. The anterior laminate cardinal tooth of the left valve is normally perpendicular or in alignment with the dorso-ventral axis of the shell and further it is generally widely separated from the anterior dorsal margin; however, in some individuals such a configuration does not always obtain and this cardinal tooth may become arcuate and extend quite close to the anterior dorsal margin, although always being distinctly separated from it. The terminus of the tooth may or may not be contiguous with the dorsal aspect of the anterior adductor muscle scar. Such conditions point out more than the relative instability of dental morphology in a single species; they show that the rudiments of subgeneric classification rest upon weak fundamentals and that the subgeneric taxonomy of the whole family becomes open to circumspection.

The questionable value of subgeneric traits is further made apparent when the radial lines on the external surface of the right valve are considered. These structures in *gouldiana* link it, as a member of *Clidiophora*, with *Pandorella* (=*Kennerlia*). The dental structure of *Clidiophora*, as exhibited by *gouldiana*, is slightly more complex in being thickened and more heavily expressed, but fundamentally quite similar to that of *Pandorella.*

According to Perkins (1869), *gouldiana* is abundant in muddy substrates at shallow depths in Long Island Sound. Apgar (1891) recorded the species along the coast of New Jersey where it was found in sand and mud; and Sumner, Osburn and Cole (1913) charted its occurrence and listed it as one of the commonest mollusks in Buzzards Bay and Vineyard Sound. In the Woods Hole vicinity, specimens were found living in from 3 to 19 fathoms, predominantly in mud, sand or muddy-sand substrates, although it was mentioned that specimens were sometimes found on gravelly substrates. We have taken *gouldiana* in considerable numbers on the pebbly bottom off Block Island, and at numerous stations along the middle Atlantic in a variety of bottom substrates. A tabulation of specimens obtained in the living state shows that the species may be found in depths down to 100 fathoms. Gould (1841) mentioned that it is often encountered nestling among and upon oysters.

Perkins (1869) and Morse (1919) have discussed briefly some aspects of the anatomy of *gouldiana.* The former mentions that the individuals are filled with ova in April and May; and Sullivan (1948), who unfortunately could not observe the larva, showed that the prodissoconch is very long in proportion to its height. Observations on the eggs of *gouldiana* have been given earlier (see page 185). The species is hermaphroditic and spawning occurs in late spring or early summer. The trochophore and veliger periods are probably short (Allen, 1961). For a discussion of the gross morphology of this species, see the anatomical notes (pl. 115).

The fossil history of *gouldiana* is extensive. An immediate precursor which is found in the Miocene is *Pandora crassidens* Conrad with its contemporaneous related forms *Pandora crassidens majorina* Gardner and *Pandora prodromos* Gardner and Aldrich. Gardner (1943) has given a thorough discussion of the morphological interrelationships among these fossils, all of which may be construed as belonging to the lineage of the modern species *gouldiana*. From the Pliocene of Florida, Olsson and Harbison (1953) have identified *crassidens*, and from the Pleistocene, Blake (1953) and Richards (1962) have listed localities in Massachusetts, New Jersey, and Maryland for *gouldiana*.

*Range.* This species has been found in Canadian waters as far north as Gaspé, Quebec and is commonly encountered southward along the Atlantic coast to Cape Hatteras, North Carolina in depths to 100 fathoms.

*Specimens examined.* Quebec: Gaspé (USNM). New Brunswick: Escuminac Point; Sand Island (both USNM). Prince Edward Island: Malpeque Bay (live) (MCZ); Cape Egmont (live) (USNM). Cape Breton Island: Eastern Harbour, Cheticamp, in 2–4 fathoms (USNM). Nova Scotia: Macoun, in 5–13 fathoms (USNM); Banquereau Bank, in 80 fathoms (live) (MCZ); Digby (USNM). Maine: St. Croix River (MCZ); Frenchman's Bay (live) (MCZ); Blue Hill Bay; Penobscot Bay; Bakers Island, in 20 fathoms (live) (all USNM); North Haven (live) (MCZ); west side of Harpswell Island (USNM); Eastern Point, west side of Chebeague Island (live); High Pine Ledge (live) (both MCZ); *Bache*, Station 42B, 6 miles SE of Boon Island (43°05′ N; 70°28′ W), in 68 fathoms (live) (USNM). Massachusetts: Tillies Bank, in 78 fathoms (live); Marblehead (live): Swampscott (all MCZ); Winthrop; Chelsea (both USNM); Stellwagen Bank (live); Garnet Ledge, Duxbury (live) (both MCZ); Eastham (live) (MCZ); Cape Cod Bay, 8 miles off Wellfleet, in 15 fathoms (live); Truro (both USNM); Provincetown (live); Dennisport (live); Poponesset Beach, Mashpee (live) (all MCZ); Woods Hole (live); *Fish Hawk*, Station 1211, north end of Woods Hole, in 6–8½ fathoms; off North Falmouth, in 6 fathoms (live) (all USNM); *Asterias*, Station E, Buzzards Bay (live) (BCF); New Bedford; *Blake*, Station 308, 200 miles E of Cape Cod (41°24′ N; 65°35′ W), in 1242 fathoms (both USNM); *Albatross* III, cruise 101, Station 89, central Georges Bank (41°29′ N; 67°28′ W), in 23 fathoms (BCF); East Georges Bank (41°20′ N; 66°50′ W), in 37 fathoms (in fish stomach) (MCZ); *Fish Hawk*, Station 1240, SSE of Gayhead Light, in 18½ fathoms (USNM); off Gay Head, in 75–100 fathoms (live) (MCZ); *Albatross* III, cruise 70, Station 4, 60 miles E of Nantucket (41°06′ N; 68°38′ W), in 26 fathoms; *Albatross* III, cruise 70, 17 miles SE of Nantucket (41° 01′ N; 69°42′ W), in 20 fathoms (both BCF). Rhode Island: Tiverton; Sakonett River, 6 miles S of Tiverton, in 2–3 fathoms (live) (both MCZ); *Fish Hawk*, Stations 786 and 787, off Newport, in 19 fathoms (live) (USNM); Watch Hill; off Block Island (live) (both MCZ); *Delaware*, cruise 62-7, Station 62, 12 miles SE of Block Island (41° 01′ N; 71°19′ W), in 29 fathoms (live, with eggs, June 19, 1962); *Delaware*, cruise 62-7, Station 64, 14 miles S of Block Island (41°00′ N; 71°30′ W), in 30 fathoms (both BCF). Connecticut: Long Island Sound, off Stonington (live); off Fishers Island, 6 miles S of New London (live) (both MCZ); *Bluelight*, Station 423, Fishers Island Sound, in 17 fathoms; *Fish Hawk*, Station 1624, 3 miles S of Bridgeport, in 5 fathoms (live) both USNM). New York: Peconic Bay, Long Island (USNM); *Delaware*, Station 2–1, alt. tow 53, 7 miles SE of Montauk Point, Long Island (40°58′ N; 71°44′ W), in 26 fathoms (live); Northport, Long Island (both MCZ); Hempstead Harbor, Long Island (USNM); Coney Island; *Delaware*, Station 3–2, alt. tow 38, 19 miles SE of Moriches Inlet (39°49′ N; 72°57′ W), in 36 fathoms (live) (both MCZ). New Jersey:

*Delaware*, Station 3–2, alt. tow 33, 40 miles E of Barnegat Inlet (39°39′ N; 73°12′ W), in 22 fathoms (live); *Delaware*, Station 3, tow 3, 65 miles E of Atlantic City (39°08′N; 73°08′ W), in 40 fathoms (all MCZ); Cape May (USNM); *Delaware*, Station 4–3, alt. tow 27, 75 miles E of Cape May (38°52′ N; 73°23′ W), in 36 fathoms (live) (MCZ). DELAWARE: Lower Middle Shoal, Delaware Bay, in 3 fathoms (live); off Lewes, in 3½ fathoms (live) (both USNM); *Delaware*, Station 4–3, alt. tow 24, 69 miles E of Indian River Inlet, (38°32′ N; 73°31′ W), in 46 fathoms (live) (MCZ). MARYLAND: *Delaware*, Station 4–5, alt. tow 1, 47 miles E of Ocean City (38°04′ N; 74°06′ W), in 41 fathoms (live) (MCZ). VIRGINIA: *Delaware*, Station 5–4, alt. tow 20, 48 miles E of Assateague Cove (37°50′ N; 74°23′ W), in 35 fathoms (live); *Delaware*, Station 5, tow 3, 49 miles E of Metomkin Inlet (37°39′ N; 74°23′ W), in 40 fathoms (live); *Delaware*, Station 6–5, alt. tow 17, 56 miles E of Cape Charles (37°05′ N; 74°48′ W), in 34 fathoms (live); *Delaware*, Station 6, tow 3, 60 miles E of Cape Henry (36°51′ N; 74°45′ W), in 40 fathoms (live); *Delaware*, Station 6–7, alt. tow 5, 53 miles E of False Cape (36°44′ N; 74°48′ W), in 35 fathoms (all MCZ). NORTH CAROLINA: *Delaware*, Station 8–7, alt. tow 11, 23 miles E of Bodie Island (35°59′ N; 75°04′ W), in 18 fathoms (live); *Delaware*, Station 7–8, alt. tow 8, 31 miles E of Bodie Island (35°54′ N; 74°55′ W), in 36 fathoms (live) (both MCZ).

## Pandora (Clidiophora) trilineata *Say*

Plate 121, figs. 1–3

*Pandora trilineata* Say 1822, Jour. Acad. Nat. Sci. Philadelphia, 1st Ser., **2**: 261; 1830, American Conchology, pl. 2 (Great Egg Harbor, New Jersey; types not seen, not in ANSP).

*Pandora nasuta* Sowerby 1830, Species Conchyliorum, *Pandora*, pl. 1, figs. 18, 19 (locality unknown; types not seen).

*Clidiophora trilineata* Say. Carpenter 1864, Proc. Zool. Soc. London, p. 597.

*Clidiophora nasuta* Sowerby. Carpenter 1864, Proc. Zool. Soc. London, p. 597.

*Pandora* (*Clidiophora*) *trilineata* Say. Dall 1886, Bull. Mus. Comp. Zool. **12**: 311.

*Pandora* (*Clidiophora*) *floridana* Dall 1886, Bull. Mus. Comp. Zool. **12**: 312 [*nomen nudum*].

*Pandora* (*Clidiphora*) *trilineata* Say. Johnson 1934, Proc. Boston Soc. Nat. Hist. **40**(1): 31, error for *Clidiophora* Carpenter.

*Description*. Shell extending to 30 mm. in length (about 1¼ inches) and to 14 mm. in height (about ⅝ inch), somewhat compressed, subsolid, inequilateral, inequivalve with the left valve overlapping the right ventrally, but both valves are weakly convex. Umbos in the anterior fourth or fifth of the valve, elevated, pointed and conspicuous. Anterior margin broadly convex, markedly distinguished from the ventral margin at the anterior radial sulcus; ventral margin smoothly rounded, convex, rising behind, slightly indented and contracted beneath the rostrum. Anterior dorsal margin short, straight to concave, generally not smoothly confluent with the anterior margin in young individuals; posterior dorsal margin elongate, concave and arcuate; posterior margin very short, forming the pointed terminus of the rostrum. In the left valve, two strong radial ridges with an intermediate sulcus extending from the umbo posteriorly; these ridges define the rostrum behind; an anterior radial sulcus extends in a dorso-ventral arcuation and delimits ventrally the confluence of the anterior and ventral margins. In the right valve, two radial and concomitant sulci extend posteriorly from the umbo; anterior radial sulcus arcuate and more or less obscure. Concentric sculpture consisting of irregular and weak lirations; the valves generally appear to be smooth. Hinge with an internal resilium and lithodesma. In the left valve, the dentition consists of an anterior lateral tooth which is strong and extends parallel to the dorso-ventral axis, of a weak rib-like central tooth and of an obsolete posterior tooth. In the right valve, the dentition consists of an obsolete straight anterior ridge-like tooth, a central thickened pedunculate tooth and a long thin posterior tooth on the under surface of which rests the resilium. Adductor muscle scars rather large, rounded and well impressed. Pallial sinus consists of irregular individual scars extending between the anterior adductor and posterior adductor muscle scars. Shell white, sometimes vitreous and transparent; nacreous internally.

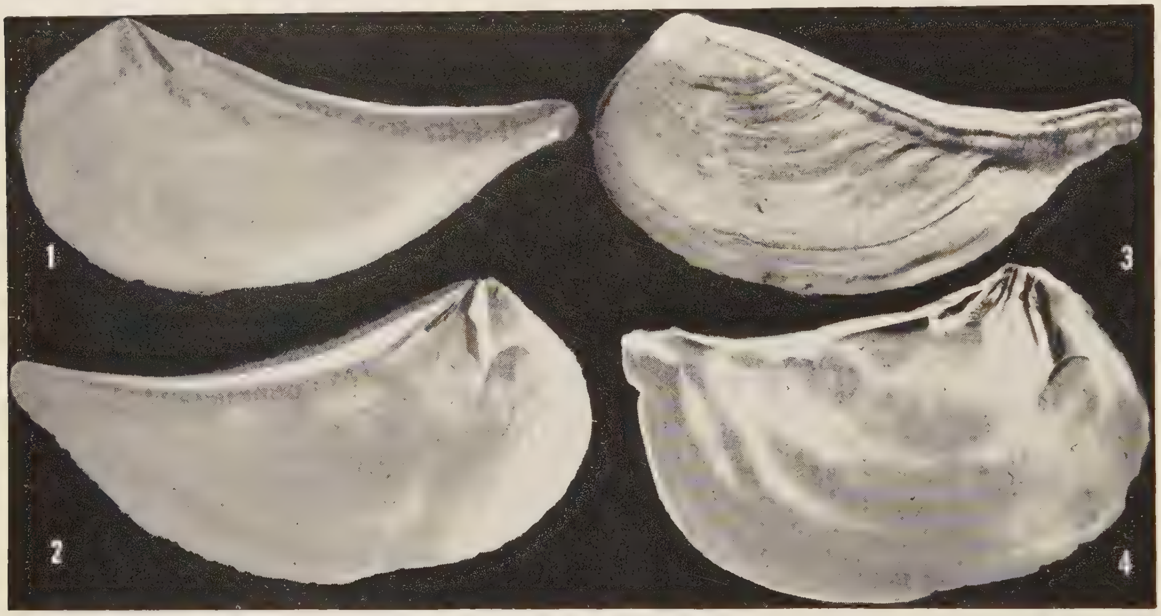

Plate 121. Figs. 1, 2 and 3. *Pandora* (*Clidiophora*) *trilineata* Say 1822. USNM 61028, Tampa, Florida, in 6 fathoms. Fig. 1. Internal view of the right valve (about 3.8x). Fig. 2. Internal view of the left valve (about 3.8x). Fig. 3. External view of the left valve (about 4.5x). Fig. 4. *Pandora* (*Clidiophora*) *gouldiana* Dall 1886. Internal view of the left valve of a paratype, USNM 95490, Woods Hole, Massachusetts (about 2.4x). (Specimen sprayed with ammonium chloride vapor.)

| length | height | width | |
|---|---|---|---|
| 19/20 in. | 9/20 in. | ?? | Holotype of *trilineata* Say (original measurements) |
| 29.3 mm. | 13.8 mm. | — | Pensacola, Florida |
| 23.6 | 10.6 | 1.9 mm. | *Eolis*, Station 21, off Beaufort, North Carolina |
| 19.9 | 8.9 | 1.9 | Tampa, Florida |
| 17.9 | 7.8 | 1.7 | " " |
| 14.8 | 5.8 | 1.4 | Matagorda Bay, Texas |
| 14.1 | 6.6 | 1.6 | *Fish Hawk*, Station 8338, off Butler's Bluff, Chesapeake Bay |
| 11.0 | 5.1 | 1.3 | Carancahua Bay, Texas |

*Remarks.* The original citation of localities by Say included the specific locality, Great Egg Harbor, New Jersey, as well as the general locality "the coast of Georgia and East Florida." The specimen figured is the elongate, slender species which is found in the south but not in the north. The differences between northern and southern species were detected by Gould, who suggested that Say's figure was incorrect in its representation of the species in Massachusetts. Dall recognized that a subrectangular, more roughly sculptured species inhabited northern waters while a sharply rostrate, narrowly arcuate species was found in the south.

Today the close propinquity of *trilineata* and *gouldiana* is recognized. A full account of the differences which serve to distinguish these species has been given under Remarks on *gouldiana* (see p. 192).

The separation of these two closely related species in their allopatric distributions may be dated from the Miocene. Gardner (1943) has discussed the *Clidiophora* of the Miocene and Pliocene formations and has shown that *Pandora toumeyi* Gardner and Aldrich appears to be an early representative in the lineage of *trilineata*. Dall (1903) gives a number of Miocene, Pliocene and Pleistocene localities for *trilineata* and its precursors. Maury (1920) has listed this species in the Pleistocene near New Orleans, and Richards (1962) has given a number of Pleistocene localities along the Atlantic coastal plain. The consolidation of the dentition into more definitive structures and into more stable configurations appears to be a trend in the evolution of this species since the Miocene.

*Pandora trilineata* is found in shallow waters from 1 to 24 fathoms, most often in mud substrates, but the species also occurs in sandy bottoms and even in shell-gravel substrates. Parker (1956, 1959) and Ladd (1951) have shown that the species appears to be most abundant in conditions of high salinities in the passes and protected bays along the Texas coast.

*Range. Pandora trilineata* is found north of Cape Hatteras as far as Chesapeake Bay. It occurs south through Florida and in the Gulf of Mexico to Port Aransas in western Texas.

*Specimens examined.* VIRGINIA: *Fish Hawk*, Station 8595, Chesapeake Bay, in 12 fathoms; *Fish Hawk*, Station 8338, off Butler's Bluff, Chesapeake Bay, in 3¾ fathoms; *Fish Hawk*, Station 8500, off Cape Henry, Chesapeake Bay, in 9 fathoms (all USNM); *Delaware*, Station 6, tow 2, 50 miles E of Cape Henry (36°53′ N; 74°59′ W), in 20 fathoms (MCZ). NORTH CAROLINA: *Delaware*, Station 8–7, alt. tow 10, 35 miles NE of Cape Hatteras (35°32′ N; 74°57′ W), in 24 fathoms (live); *Delaware*, Station 8, tow 1, 18 miles NE of Cape Hatteras (35°24′ N; 75°12′ W), in 14 fathoms (live) (both MCZ); *Albatross* I, Station 2597, 20 miles E of Swash Inlet, between Cape Hatteras and Cape Lookout (34°57′ N; 75°43′ W), in 15 fathoms; shoals west of Pivers Island (near Beaufort); *Eolis*, Station 21, off Beaufort, in 6–9 fathoms; *Albatross* I, Station 2619, 25 miles SE of Cape Fear (33°38′ N; 77°36′ W), in 15 fathoms (all USNM). SOUTH CAROLINA: Charleston (MCZ); Beaufort (USNM). FLORIDA: Manatee River; 3¾ miles SSW off Longboat Pass, Manatee County, in 6 fathoms (both USNM); Tampa Bay (live) (MCZ); Tampa, in 6 fathoms (USNM); Pensacola (MCZ; USNM). TEXAS: Galveston (MCZ); Matagorda Bay; Carancahua Bay; Pass Cabello, Matagorda Island (all USNM); Port Aransas (MCZ).

## **Pandora (Clidiophora) inornata** *Verrill and Bush*

Plate 120, figs. 1–2

*Clidiophora inornata* Verrill and Bush 1898, Proc. U.S. Nat. Mus. **20**: 819, pl. 95, figs. 5 and 6 (*Speedwell*, Station 327, off Cape Cod, south end of Stellwagen Bank, in 17 fathoms; syntypes, USNM 49760).

*Pandora* (*Clidiophora*) *inornata* Verrill and Bush. Johnson 1915, Occ. Pap. Boston Soc. Nat. Hist. **13**: 38.

*Pandora* (*Clidiphora*) *inornata* Verrill and Bush. Johnson 1934, Proc. Boston Soc. Nat. Hist. **40**(1): 31 [error for *Clidiophora* Carpenter].

*Description.* Shell extending to 19 mm. in length (about ¾ inch) and to 12 mm. in height (about ½ inch), elongate, rostrate posteriorly and rounded anteriorly, inequilateral, inequivalve with the left valve convex and the right valve more or less flattened. Umbos in the anterior third of the shell blunt, rounded and inflated in the left valve. Anterior margin broadly rounded and smoothly confluent with the ventral margin; ventral margin gently convex, rising and straight to indented behind; anterior dorsal margin convex and smoothly confluent with the anterior margin; posterior dorsal margin long and slightly concave; posterior margin short and more or less straight and forming an oblique truncation. In the left valve, two weak, divaricating, external, radial ridges posteriorly, the ventral ridge the stronger, and with a weak sulcus separating it from the dorsal ridge. Anterior radial sulcus in the left valve weak, not disrupting the ventral contour of the shell but delimiting the confluence of the anterior margin and the ventral margin. Concentric sculpture weak; coarse growth rings strongly evident, particularly on the left valve. Hinge with a lithodesma, an internal resilium and external ligament. Dentition of the left valve with a strong, thickened anterior cardinal tooth with an excavation above; central cardinal tooth small but developed; posterior lateral tooth consists of a subproximal thickening of the hingeline. Dentition of right valve with a strong, elongate posterior cardinal tooth and a central thickened sublunate, pedunculate cardinal tooth; anterior cardinal tooth consists of an obscure thickening, extending from the umbo to the anterior adductor muscle scar. Adductor muscle scars well impressed, moderately large, subrhomboid to elongate-ovate in shape. Pallial sinus consisting of irregular, individual scars extending between the anterior and posterior adductor muscle scars. Shell white, internally nacreous, externally dirty-white to a light brown and somewhat glabrous.

| length | height | width | |
|---|---|---|---|
| 16.7 mm. | 10.1 mm. | 3.4 mm. | Syntype of *inornata* Verrill and Bush |
| 18.8 | 11.6 | 3.6 | *Speedwell*, Station 251, off Race Point Light |
| 18.5 | 12.0 | 4.0 | " " " " " " " |
| 15.1 | 10.1 | 3.8 | " " " " " " " |
| 12.0 | 6.9 | 2.2 | *Bache*, Station 33B, Stellwagen Bank |
| 11.3 | 6.7 | 2.0 | *Speedwell*, Station 327, S end of Stellwagen Bank |
| 10.2 | 5.2 | 1.7 | *Speedwell*, Station 251, off Race Point Light |

*Remarks. Pandora inornata* is a comparatively rare species of limited geographical distribution. It is easily confused with its close ally, *P. gouldiana* Dall, and, for this reason, has often remained undetected in collections. Both *inornata* and *gouldiana* belong to the subgenus *Clidiophora*, but *inornata* is much more stable in its traits and its range of variation is not as great as that of *gouldiana*. *Pandora inornata* is thicker, more heavily shelled in its youthful stages, stronger, more solid, of a smaller maximum size, of lower proportionate height, and of a less intense nacreous interior. Such traits are difficult to quantify but a closer examination of specimens usually suffices to distinguish each species.

The left anterior cardinal tooth in *inornata* is arcuate and thickened proximally; this tooth terminates distally at or near the uppermost portion of the anterior adductor muscle scar where it forms a weak ridge extending out to the border of the valve; the anterior adductor muscle scar therefore appears to be deeply impressed. In *gouldiana*, the anterior cardinal tooth generally descends along the dorso-ventral axis from the umbonal region; however, in the range of variation some specimens of *gouldiana* have an arcuate anterior cardinal tooth but its terminus is more distinct than the homologous structure in *inornata* and there does not appear to be ridge-like extensions of the tooth to the border of the valve. The anterior adductor muscle scar in such specimens of *gouldiana* does not appear to be so strongly impressed.

The anterior dorsal margin of *inornata* tends to be convex, rounded and more or less smoothly confluent with the anterior margin. In contrast, the anterior dorsal margin of *gouldiana* is usually straight or slightly concave and there is a slight flaring rather than a smooth confluence where this margin meets the anterior margin. A definitive ventral ridge and supernumerary ridges are lacking in *inornata* while along the posterior dorsal margin in *gouldiana* there is a double ridge—a strong ventral one which runs completely to the posterior ventral angulation and defines the posterior rostration, and a weaker somewhat obsolete dorsal one. Between these ridges in *gouldiana* there is a depression or weak sulcus.

*Range.* This species is localized and restricted in distribution from below Nova Scotia to the southern part of Cape Cod and has been taken alive in depths to 35 fathoms.

*Specimens examined.* Nova Scotia: 14 miles S of Cape Sable, in 45 fathoms (MCZ). Massachusetts: Jeffries Ledge, in 35 fathoms (live); off Duxbury, in 18 fathoms (live); Stellwagen Bank, in 23 and 35 fathoms (live) (all MCZ); *Bache*, Station 33B, Stellwagen Bank (42°20′ N; 70°18′ W), in 22 fathoms (live); *Speedwell*, Station 327, S end of Stellwagen Bank (42°11′ N; 70°12′ W), in 17 fathoms (live) (both USNM); *Gosnold*, Station 1209, S end of Stellwagen Bank (42°10′ N; 70°14′ W), in 20 fathoms (live) (BCF); *Speedwell*, Station 251, 6$\frac{3}{4}$ miles off Race Point Light (42°10′ N; 70°10′ W), in 24 fathoms (live) (USNM). *Jenni B*, Stations (035° true north from Provincetown monument) 37, in 14 fathoms (live); 17, in 24 fathoms (live); 19, in 30 fathoms; *Jacqueline*, Stations (064° true north from Cape Cod Light) 33, in 37 fathoms; 6, in 21 fathoms (all BCF); *Fish Hawk*, Station 964, 5 miles SE of Chatham, in 10 fathoms; *Speedwell*, Station 367, 5$\frac{1}{2}$ miles ESE of Chatham (41°38′ N; 69°49′ W), in 12 fathoms (live); *Fish Hawk*, Station 978, 6 miles ESE of Chatham, in 17 fathoms (live); *Fish Hawk*, Station 981, 16 miles ESE of Chatham Light, in 43 fathoms (all USNM).

### Subgenus **Pandorella** *Conrad*

*Pandorella* Conrad 1863, Proc. Acad. Nat. Sci. Philadelphia, for 1862, p. 572 (type species, by monotypy, *Pandora arenosa* Conrad 1834), *non* Laseron 1951.

*Kennerlia* Carpenter 1864 (Aug.), Brit. Assn. Adv. Sci. Report for 1863, pp. 602 and 638; 1864 (Nov.). Proc. Zool. Soc. London, p. 602 (type species, by subsequent designation, Stoliczka 1871, p. 61, *Pandora Kennerlia bicarinata* Carpenter 1864 [=*Pandora* (*Kennerlia*) *bilirata* Conrad 1855]).

*Kenerlia* Carpenter. Paetal 1875, Fam. Gatt. Moll., p. 103 [error for *Kennerlia* Carpenter].

*Kennerleya* Carpenter. Fischer 1887, Manuel de Conchy., p. 1158 [emend. for *Kennerlia* Carpenter].

*Kennerleyia* Carpenter. Dall 1903, Trans. Wagner Free Inst. Sci., Philadelphia **3**(6): 1517 [emend. for *Kennerlia* Carpenter].

*Kennerlyia* Carpenter. Dall 1915, Proc. U.S. Nat. Mus. **49**: 448 [error for *Kennerlia* Carpenter].

*Panderella* Conrad. Palmer 1958, Memoir 76, Geol. Soc. Amer., p. 76 [error for *Pandorella* Conrad].

Vokes (1956) has documented the usage of *Pandorella* and has shown that it is a senior synonym of *Kennerlia.* Palmer (1958), Keen (1958), and Olsson (1961) have adopted the subgeneric name *Pandorella* to replace the previously widely employed *Kennerlia.* According to Dall (1903), the characters which typify the subgenus *Pandorella* (=*Kennerlia*) include the presence of radial lines on the external surface of the right valve and an internal lithodesma or calcified supporting structure attached to the base of the resilium. Further, the dental configuration is typified by an obsolete right anterior cardinal tooth and a left anterior cardinal tooth which is adpressed to or coextensive with the anterior dorsal margin of the valve.

This subgenus, although widely distributed in the northern hemisphere, is particularly well developed in the Western Atlantic and Eastern Pacific areas. Its origin is apparently dated from the Miocene of North America.

### Pandora (Pandorella) arenosa *Conrad*

Plate 122, figs. 1–2; Plate 125, fig. 3

*Pandora arenosa* Conrad 1834, Jour. Acad. Nat. Sci. Philadelphia, 1st Ser. **7**(1): 130–131; 1838, Fossils of medial Tertiary, p. 2, pl. 1, fig. 3 (Yorktown [Miocene], Virginia; syntypes, ANSP 30584).

*Myadora arenosa* Conrad 1848, Proc. Acad. Nat. Sci. Philadelphia (for 1846) **3**: 21.

*Pandorella* (*Pandora*) *arenosa* Conrad 1863, Proc. Acad. Nat. Sci. Philadelphia (for 1862), 2nd Ser. **6**: 572.

*Pandora oblonga* 'Sowerby' Dall 1881, Bull. Mus. Comp. Zool. **9**: 109, *non* Sowerby 1830.

*Pandora* sp. Bush 1885, Report U.S. Comm. Fish and Fisheries for 1883, p. 86.

*Pandora carolinensis* Bush 1885, Trans. Conn. Acad. **6**(2): 474 (USFC *Albatross* I, Station 2113, off Cape Hatteras, North Carolina, in 15 fathoms; holotype, USNM 35701).

*Pandora carolininensis* Bush. Dall 1885, Bull. U.S. Geol. Sur., no. 24, p. 213 (error for *carolinensis* Bush).

*Pandora* (*Clidiophora*) *carolinensis* Bush. Dall 1886, Bull. Mus. Comp. Zool. **12**(6): 311, pl. 8, figs. 8–8a.

*Pandora* (*Kennerleyia*) *arenosa* Conrad. Dall 1903, Trans. Wagner Free Inst. Sci. Philadelphia **3**(6): 1518.

*Pandora* (*Kennerleya*) *arenosa* Conrad. Maury 1920, Bull. Amer. Paleo. **8**(34): 40.

*Pandora* (*Kennerlia*) *arenosa* Conrad. Johnson 1934, Proc. Boston Soc. Nat. Hist. **40**(1): 31; Gardner 1943, Geol. Sur. Prof. Paper 199-A, p. 45, pl. 10, figs. 16, 19, 20.

*Pandora* (*Pandorella*) *arenosa* Conrad. Olsson 1961, Panamic-Pacific Pelecypoda, Ithaca, N.Y., p. 454.

*Description.* Shell extending to 20 mm. in length (about 4/5 inch) and to 12 mm. in height (about 1/2 inch), subelliptical, solid, inequilateral and inequivalve with the left valve markedly convex and the right valve weakly concave. Umbos far anterior, in the anterior fifth of the total shell length, weakly pointed and prosogyrous. Anterior margin narrowly rounded, uniting in an indentation with the ventral margin at the anterior radial sulcus. Ventral margin broadly convex, rising arcuately and with an indentation behind. Anterior dorsal margin weakly convex in the left valve, weakly concave in the right. Posterior dorsal margin long, gently inclined, descending along its length and somewhat concave far posteriorly. Posterior margin short, oblique and irregular, forming a blunt rostrate truncation. Left valve with an external posterior curvilinear ridge extending from the umbo to the base of the posterior margin and delineating the posterior slope as well as the posterior rostration. An interior radial sulcus extends from the umbo ventrally, dividing the anterior margin and the ventral margin. Along this sulcus the concentric sculpture is depressed. Right valve with an external radial ridge dorsally, and directly ventral to it, a strong radial sulcus. Concentric sculpture consisting of closely spaced, fine lirations, stronger in the left valve and flexed along the anterior radial sulcus. Radial lines occur in the right valve. Hinge with a lithodesma, an internal resilium, and an external ligament, particularly evident along the anterior dorsal margin of the left valve. Dentition of the right valve consists of a thickened, moderately elongate posterior cardinal tooth, a central rectangular pedunculate cardinal tooth, and an obscure anterior thickening representing the anterior cardinal tooth. Dentition of the left valve consists of a thickened, horizontal tooth above which is a concave excavation, a central thin cardinal tooth in the resilial complex and the posterior cardinal tooth which consists of a thickening of the posterior dorsal margin. Adductor muscle scars impressed, small and subcircular; the anterior adductor muscle scar in the left valve partly obscured under the concavity of the anterior lamina. Pallial line consisting of individual and numerous, well impressed scars, forming a series of punctations extending between the an-

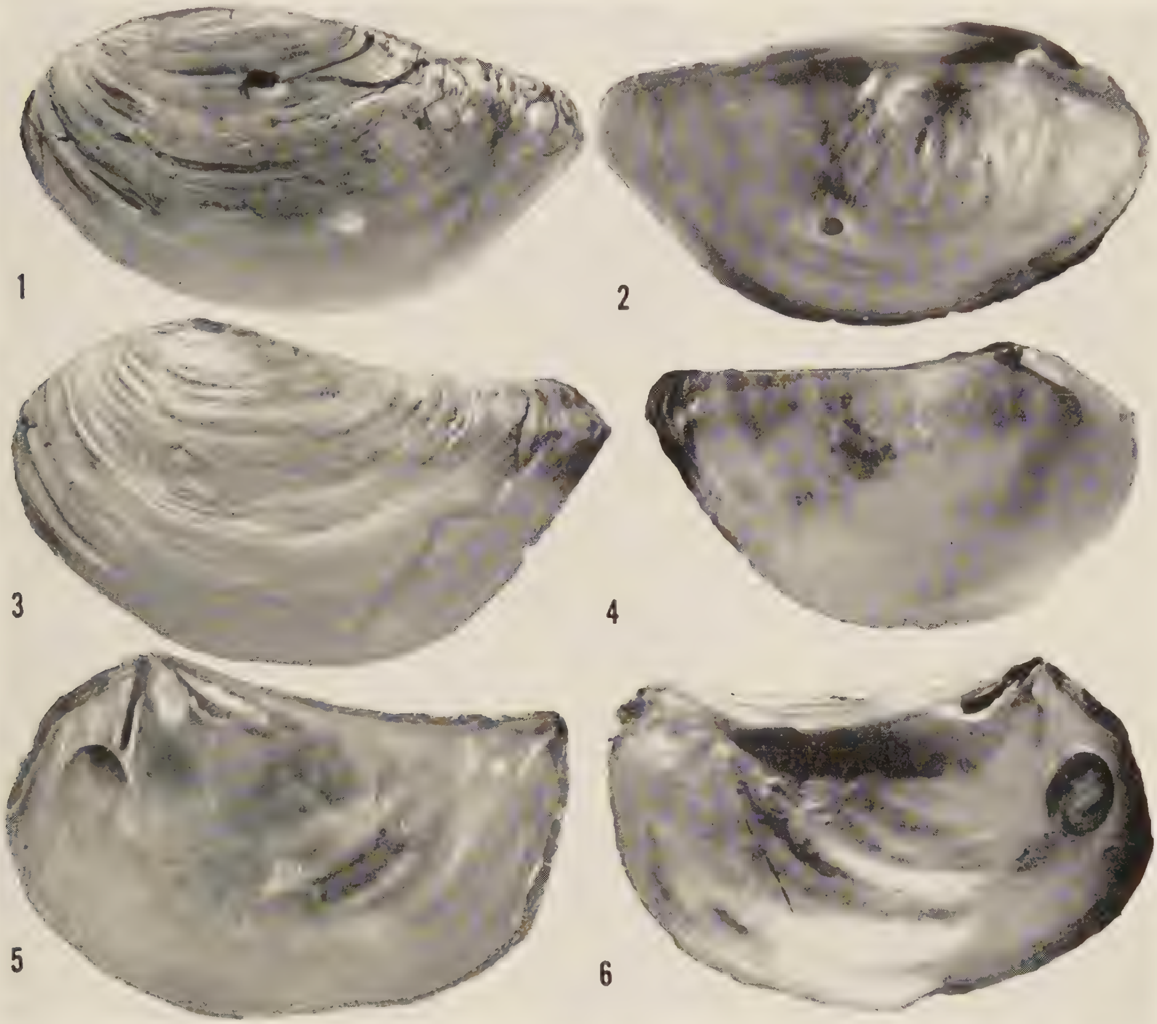

Plate 122. Figs. 1 and 2. *Pandora carolinensis* Bush 1855 [=*Pandora* (*Pandorella*) *arenosa* Conrad 1834]. USNM 35701, *Albatross* I, Station 2113, off Cape Hatteras, North Carolina, in 15 fathoms. Fig. 1. External view of the left valve of the holotype (about 5.8x). Fig. 2. Internal view of the left valve of the holotype (about 5.8x). Figs. 3 and 4. *Pandora* (*Kennerlyia*) *glacialis* var. *eutaenia* Dall 1915 [=*Pandora* (*Pandorella*) *glacialis* Leach 1819]. USNM 171062, Sitka Harbor, Alaska, in 15 fathoms. Fig. 3. External view of the left valve of a syntype (about 2.8x). Fig. 4. Internal view of the left valve of a syntype (about 3x). Figs. 5 and 6. *Pandora* (*Clidiophora*) *gouldiana* Dall 1886. USNM 95490, Woods Hole, Massachusetts. Fig. 5. Internal view of the right valve of a paratype (about 3x). Fig. 6. External view of the left valve of a paratype (about 2.6x).

terior adductor and posterior adductor muscle scars. Shell white, highly shining and nacreous internally, dull, somewhat chalky and slightly eroded externally.

| length | height | width | |
|---|---|---|---|
| 13.5 mm. | 7.5 mm. | 2.6 mm. | Holotype of *carolinensis* Bush |
| 19.4 | 11.3 | 4.0 | *Albatross* I, Station 20011, off Vero Beach, Florida |
| 19.0 | 11.1 | — | “ “ “ “ “ “ “ |
| 18.0 | 11.6 | — | “ “ “ “ “ “ “ |
| 16.7 | 9.1 | 2.9 | *Albatross* I, Station 2277, off Cape Hatteras, N.C. |
| 15.0 | 8.5 | 3.1 | “ “ “ “ “ “ “ |
| 8.3 | 4.1 | — | *Albatross* I, Station 2112, off Cape Hatteras, N.C. |
| 7.1 | 3.3 | — | *Albatross* I, Station 2114, off Cape Hatteras, N.C. |

*Remarks. Pandora arenosa* is small and heavily shelled. It is primarily characterized by its highly nacreous interior and its strong convexity of the left valve. In the Western Atlantic it may be confused with *Pandora bushiana* Dall. From the latter, which is its nearest relative in this area, *arenosa* may be distinguished by its strongly curvilinear posterior radial ridge, its more rostrate form and its thicker and heavier shell. *Pandora bushiana* tends to be more narrowly elongate and more compressed than *arenosa* and it is not as nacreous. Immature or small individuals of *arenosa* do not possess the ventral inflation of the adults and they are of more narrow proportions, being somewhat lanceolate in outline. Such young specimens might easily be confused with *bushiana*, but they may be distinguished specifically by their strong rotundity and their developed left anterior cardinal tooth. *Pandora inflata* (=*brevis* Verrill and Bush) which also may be confused with *arenosa* is thin and in some cases translucent; its posterior margin is blunt and not rostrate; its radial posterior ridge is not curvilinear, is generally more widely removed from the posterior dorsal margin and is also not completely carinate to the posterior margin.

*Pandora arenosa* has some structural features in common with *Pandora filosa* Carpenter of the Pacific Northwest, but *filosa* is not as strongly enrolled (convex in the left valve), nor does it possess as distinct a posterior ridge.

The original description of *Pandora carolinensis* Bush is incorrect in its orientation of the anterior and posterior parts of the animal and the shell, that is, directions are reversed. The first figure for *carolinensis* Bush is that of Dall (1886, pl. 8, figs. 8a–b) and it compares with the type figure of *arenosa* Conrad. Dall first synonymized *carolinensis* with *arenosa* and there appears to be no question concerning this treatment.

The fossil history of *arenosa* begins in the Miocene. Indeed, the recent species is based on Conrad's description of a shell from the Miocene of Yorktown, Virginia. A number of other named fossil forms represent very close relatives of *arenosa*. In Miocene formations, these include *Pandora dodona* Dall from the Oak Grove Sands of Florida, *Pandora lata* Dall from St. Mary's, Maryland, and *Pandora dalli* Gardner from the St. Mary's formation, Virginia. *Pandora naviculoides* Gardner is another close ally from the Pliocene Waccamaw formation, North Carolina. *Pandora arenosa* has also been recorded from the Pliocene of the Caloosahatchee marl, Shell Creek, Florida (Maury, 1920) and from the Pleistocene of North Carolina (Richards, 1962).

This species was very well represented in the *Albatross* dredgings off Cape Hatteras, but rarely was the species encountered alive. Off Florida where known living specimens have been collected, the species appears to prefer a coarse substrate in shallow water.

*Range.* *Pandora arenosa* is found from off Currituck Beach, North Carolina south to the Gulf of Mexico as far west as Texas and as far south as Yucatan, Mexico, in depths to 20 fathoms (live) and 640 fathoms (dead). Perry and Schwengel (1955) have reported it off Sanibel Island in the Gulf of Mexico from 4–6 fathoms. Singley (1893) and Pulley (1952) have recorded it from Texas.

*Specimens examined.* NORTH CAROLINA: *Delaware*, Station 7–6, alt. tow 12, 44 miles E of Currituck Beach (36°19′ N; 74°55′ W), in 29 fathoms (MCZ); *Albatross* I, Station 2307, 30 miles ESE of Oregon Inlet (35°42′ N; 74°54′ W), in 43 fathoms (USNM); *Albatross* I, Station 2112, 12 miles ENE of Cape Hatteras (35°20′ N; 75°18′ W), in 15 fathoms; *Albatross* I, Station 2277, 9½ miles ENE of Cape Hatteras (35°20′ N; 75°19′ W), in 16 fathoms; *Albatross* I, Station 2113, 8 miles ENE of Cape Hatteras (35°20′ N; 75°19′ W), in 15 fathoms; *Albatross* I, Station 2114, 11 miles E of Cape Hatteras (35°20′ N; 75°20′ W), in 14 fathoms; *Albatross* I, Station 2615, 28 miles SE of Cape Fear (33°45′ N; 77°25′ W), in 18 fathoms (live) (all USNM). SOUTH CAROLINA: *Miss Kim*, Station 9, 37½ miles, 130° off Sandy Point, Raccoon Key (32°28′ N; 78°47′ W), in 20 fathoms (live) (MCZ). FLORIDA: *Albatross* I, Station 20011, off Vero Beach, in 46 fathoms (USNM); off Sanibel Island, in 6 fathoms; off Charlotte Harbor, in 13 fathoms (both MCZ); Sarasota Bay (live); 3¾ miles SSW of Longboat Pass, Manatee County, in 6 fathoms (live) (both USNM); 120 miles W of Clearwater, in 34–36 fathoms (MCZ). MEXICO: *Albatross* I, Station 2361, off Cabo Catoche, Yucatan (22°08′ N; 86°51′ W) (USNM); *Blake*, Yucatan Strait, in 640 fathoms (MCZ).

### Pandora (Pandorella) bushiana *Dall*

Plate 123, figs. 1–3

*Pandora* (*Kennerlia*) *bushiana* Dall 1886, Bull. Mus. Comp. Zool. **12**(6): 312 (Tampa, Florida, in 6 fathoms; holotype, USNM 61029).

*Pandora* (*Kennerleyia*) *bushiana* Dall 1902, Proc. United States Nat. Mus. **24**: 511, pl. 31, fig. 3.

*Pandora* (*Kennerleya*) *bushiana* Dall. Maury 1920, Bull. American Paleo. **8**(34): 40.

*Description.* Shell extending to 16 mm. in length (about [illegible] inch) and to 8 mm. (about ⅜ inch) in height, thin to fragile, narrowly elongate, inequilateral, inequivalve with the left valve convex and the right valve somewhat concave. Umbos placed in the anterior fifth of the valve, small and pointed. Anterior margin narrowly rounded, weakly convex, and with an indentation becoming confluent with the ventral margin at the anterior radial sulcus; ventral margin broadly rounded, convex, rising posteriorly and sometimes indented posteriorly; anterior dorsal margin somewhat concave, sigmoid, and descending; posterior dorsal margin very long, weakly convex, gently descending and sometimes weakly ascending posteriorly; posterior margin short, irregular and forming a blunt subrostrate truncation. In the left valve, a single weakly carinate, subcurvilinear ridge extends from the umbo to the base of the posterior margin behind; the anterior radial sulcus nearly perpendicular and defining the confluence of the anterior margin with the ventral margin. In the right valve, two ridges dorsally and two weak radial, subsigmoid sulci extending from the umbo to the posterior margin. Concentric sculpture weak, finely incised and closely set. Hinge with an internal resilium, a lithodesma and an external ligament. Dentition of left valve with a flattened, partly protruding anterior cardinal tooth with a concave surface; the external ligamental area, excavated above this tooth, is very narrow; central cardinal weak, fine, and bordering the resilial pit; posterior cardinal tooth long, thin, laminate and coextensive with the thickened hinge line. Dentition of right valve with a long thin posterior cardinal tooth, a narrow pedunculate central cardinal tooth; no true anterior cardinal tooth, but localized thickenings along the anterior dorsal margin and near the anterior adductor muscle scar do occur. Adductor muscle scars well impressed and rounded. Pallial sinus consists of individual scars extending between the anterior muscle scar and the posterior adductor muscle scar. Shell white, covered with a brownish white periostracum with superficial radiations evident externally on the left valve, nacreous but not highly shining internally.

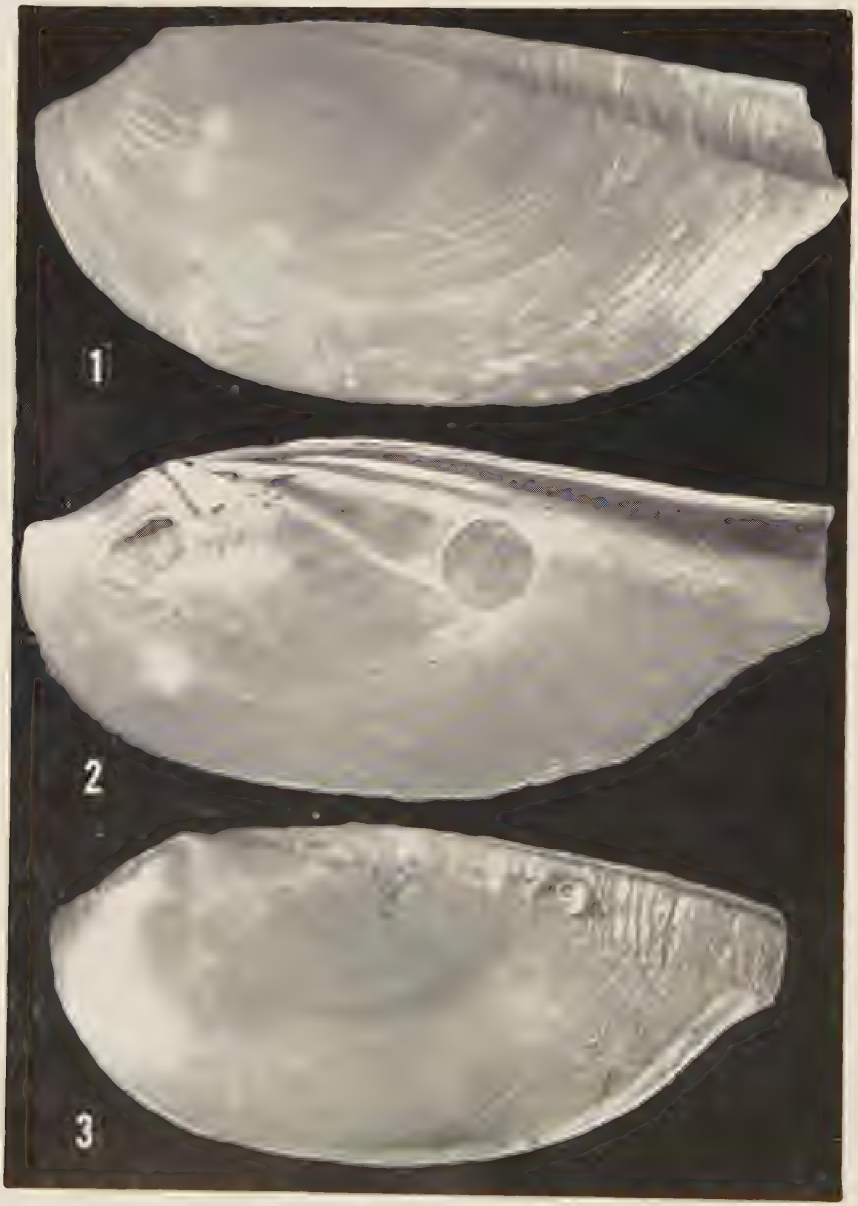

Plate 123. Figs. 1 and 2. *Pandora* (*Pandorella*) *bushiana* Dall 1886. USNM 599331, off Destin, Florida, in 20 fathoms. Fig. 1. External view of the left valve (about 7.3x). Fig. 2. Internal view of the right valve (about 7.4x). Fig. 3. *Pandora* (*Kennerlia*) *bushiana* Dall 1886 [= *Pandora* (*Pandorella*) *bushiana* Dall]. External view of the left valve of a syntype. USNM 61029, Tampa, Florida, in 6 fathoms (about 8.6x).

| length | height | width | |
|---|---|---|---|
| 11.5 mm. | 5.5 mm. | 1.0 mm. | Holotype of *bushiana* Dall |
| 15.2 | 7.7 | 1.8 | off Destin, Florida, in 20 fathoms |
| 11.9 | 5.2 | 1.0 | *Barrera*, Station 208, off Bahía Honda, Cuba, in 1–12 fathoms |
| 8.9 | 4.1 | 0.8 | " " " " " " " " " " |

*Remarks.* This species is rather poorly known. It appears to be a more tropical species with some distribution in the Antilles. According to Warmke and Abbott (1961), it is commonly encountered in dredgings. Established depth records for the species indicate a shallow water habitat not exceeding 25 fathoms, and Perry and Schwengel (1955) have listed its occurrence off Sanibel Island in 4–6 fathoms. Parker (1956) found it dead at eight stations in the deep shelf zone along the Texas coast.

The presence of a lithodesma and the union of the left anterior cardinal tooth with the anterior hinge line places this species within the confines of *Pandorella*. Its closest relative appears to be *Pandora arenosa* which is a more strongly and heavily shelled species. *Pandora bushiana* is less convex in the left valve and when living, is covered with a light brownish periostracum. In addition, its left anterior cardinal tooth tends to be somewhat weakened and concave. Another species with which *bushiana* may be confused is *Pandora inflata* which is swollen ventrally and broadly truncated posteriorly. According to Dall's original comments, *bushiana* possesses a convex posterior dorsal margin and its rostrum points ventrally. Both these traits may be observed in the species but they are neither constant nor diagnostic.

*Range.* *Pandora bushiana* occurs from off Cape Fear, North Carolina south through the Florida Keys to the northern part of Florida, the Bahama Islands, Cuba and south to Yucatan. It has been found living in depths to 25 fathoms.

*Specimens examined.* NORTH CAROLINA: *Albatross* I, Station 2615, 27 miles ESE of Cape Fear (33°45′ N; 77°25′ W), in 18 fathoms (live) (USNM). SOUTH CAROLINA: *Miss Kim*, Station 9, about 37½ miles, 130° off Sandy Point, Raccoon Key (32°34′ N; 78°51′ W), in 10 fathoms (live); *Miss Kim*, Station 11, about 43¼ miles, 130° off Sandy Point, Raccoon Key (32°31′ N; 78°51′ W), in 25 fathoms (live) (both MCZ). FLORIDA: *Eolis*, Station 83, off Government Cut, Miami, in 3 fathoms (live) (USNM); 5 miles E of Carysfort Light, in 96–107 fathoms (MCZ); *Eolis*, Station 33, off Tortugas, in 16 fathoms (live) (USNM); off Sanibel Island, in 6 fathoms (live) (MCZ); off Tampa, in 6 fathoms (live) (USNM); off Destin, in 18–20 fathoms (MCZ; USNM); off Fort Walton, in 16–19 fathoms (MCZ). BAHAMAS: Moraine Cay (MCZ); *Eolis*, Station 50, N. Bimini Island, in 20 fathoms (USNM). CUBA: *Barrera*, Station 208, off Bahía Honda, in 1–12 fathoms (live) (USNM). MEXICO: *Albatross*, Station 2361, off Cabo Catoche, Yucatan (22°08′ N; 86°15′ W), in 25 fathoms (USNM).

## **Pandora (Pandorella) inflata,** new name

Plate 124, figs. 1–4; Plate 125, figs. 1–2

*Kennerlia glacialis* 'Leach' Verrill 1881, Proc. United States Nat. Mus. **3**: 397, *non* Leach 1819.

*Pandora* (*Kennerlia*) *glacialis* 'Leach' Dall 1889, Bull. United States Nat. Mus., no. 37, p. 69, *pars*, *non* Leach 1819.

*Kennerlia brevis* Verrill and Bush 1898, Proc. United States Nat. Mus. **20**: 821, pl. 88, figs. 7a–b (*Albatross* I, Station 2248, 67 fathoms, S of Nantucket, Massachusetts; holotype, USNM 40232), *non* Sowerby 1829.

*Pandora* (*Kennerlia*) *brevis* Verrill and Bush. Johnson 1934, Proc. Boston Soc. Nat. Hist. **40**(1): 31, *non* Sowerby 1829.

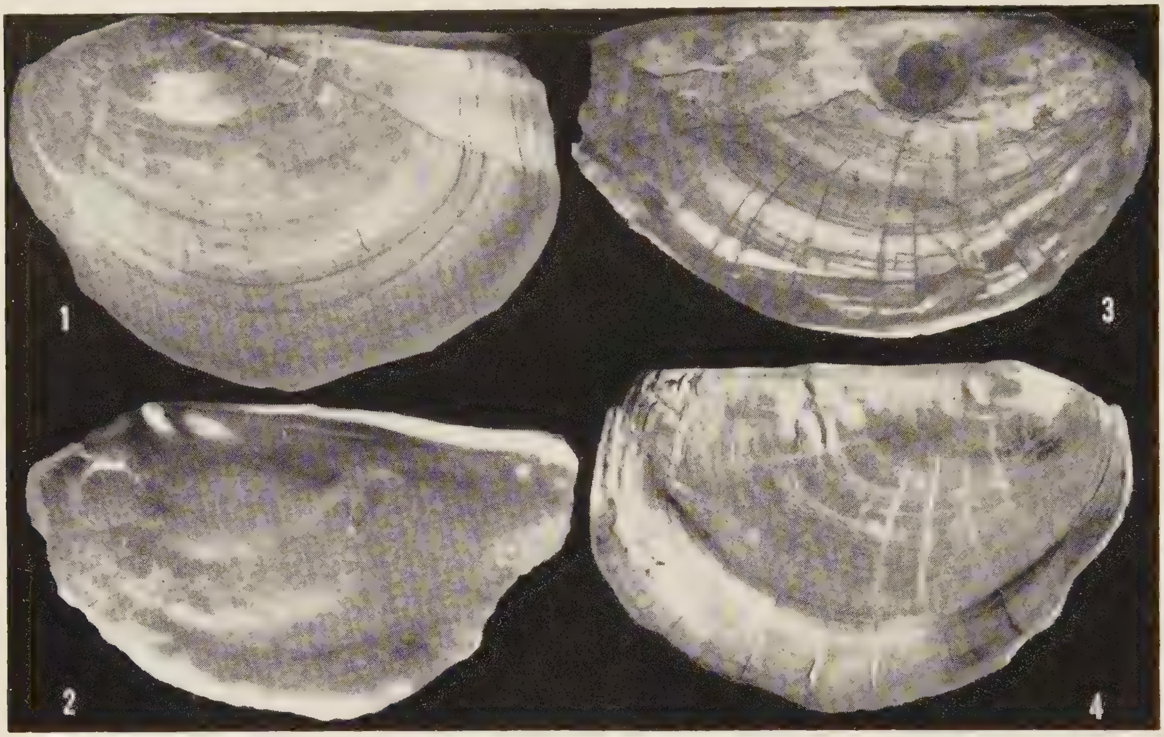

Plate 124. Figs. 1 and 2. *Pandora* (*Pandorella*) *inflata*, new name. Fig. 1. External view of the left valve. USNM 444729, *Eolis*, Station 309, off Fowey Light, Florida, in 60 fathoms (about 8.3x). Fig. 2. Internal view of the right valve. USNM 323233, *Albatross* I, Station 2369, off Cape San Blas, Florida, Gulf of Mexico, in 26 fathoms (about 6.8x). Fig. 3. *Kennerlia brevis* Verrill and Bush 1898, *non* Sowerby 1829 [= *Pandora* (*Pandorella*) *inflata*, new name]. External view of the right valve of the holotype. USNM 40232, *Albatross* I, Station 2248, S of Nantucket, Massachusetts, in 67 fathoms (about 8.3x). Fig. 4. *Pandora* (*Pandorella*) *inflata*, new name. External view of the right valve. USNM 444729, *Eolis*, Station 309, off Fowey Light, Florida, in 60 fathoms (about 7.9x).

*Description*. Shell extending to 18 mm. in length (about $\frac{3}{4}$ inch) and to 9 mm. in height (about $\frac{3}{8}$ inch), subsolid to fragile, somewhat translucent, inequilateral, inequivalve, with the left valve markedly convex and tumid and the right valve concave. Umbos situated in the anterior quarter of the valve, small and somewhat pointed. Anterior margin narrow, short, weakly convex and markedly distinct from the ventral margin; ventral margin broadly convex, rising but not indented behind; anterior dorsal margin gently descending and weakly convex; posterior dorsal margin more or less straight, long, and slightly descending; posterior margin confluent with the ventral margin, nearly straight and forming a broad blunt truncation. Left valve with a strong anterior radial sulcus which strongly delimits the confluence of the anterior margin and the ventral margin. Left valve with two radial posterior ridges, the ventral one the stronger and more carinate. The posterior ridges rarely extend all the way to the posterior margin. In the right valve there are two radial ridges along the posterior dorsal margin and ventral to these are two distinct radial sulci extending posteriorly from the umbo. Concentric sculpture consisting of closely spaced, weakly incised sulci; radial sculptural lines evident in the right valve. Hinge with an internal resilium, a lithodesma and an external ligament. Dentition of the left valve consists of a strongly curved anterior cardinal tooth with an excavated ligamental concavity above it, a resilial complex consisting of a medial ridge and an excavated resilial pit; posterior cardinal tooth a mere thickening along the posterior dorsal margin. Dentition of the right valve consists of an angular, thin posterior cardinal tooth with an internal ray beneath extending to the posterior adductor muscle scar, a straight central pedunculate tooth, no true anterior tooth, but a thickening of the anterior dorsal margin at the hinge line and a thickening dorsal to the anterior adductor muscle scar. Adductor muscle scars well impressed, small and rounded. In the left valve, the anterior adductor muscle scar is beneath the cavity of the anterior cardinal tooth. Pallial sinus consists of weak, individual, punctations extending between the anterior and posterior adductor muscle scars. Shell dirty white externally, nacreous internally and shining externally, particularly along the curvature of the left valve.

| length | height | width | |
|---|---|---|---|
| 9.0 mm. | 4.8 mm. | 1.2 mm. | Holotype of *brevis* Verrill and Bush |
| 9.3 | 5.1 | — | Paratype (right valve) of *brevis* Verrill and Bush |
| 12.6 | 8.6 | — | *Albatross* I, Station 2268, off Cape Hatteras |
| 12.1 | 8.8 | 2.3 | *Fish Hawk*, Station 920, off Manasquan Inlet, New Jersey |
| 11.3 | 7.3 | — | *Albatross* I, Station 2265, off Cape Henry, Virginia |
| 9.8 | 6.2 | 1.5 | *Eolis*, Station 151, off Government Cut, Miami, Florida |
| 6.1 | 3.3 | 0.8 | *Eolis*, Station 366, E of Ragged Key, Florida |

*Remarks.* The name *brevis*, introduced by Verrill and Bush for this species, is preoccupied by the *brevis* of Sowerby. We have chosen the descriptive name *inflata* to apply to this species. *Pandora inflata* appears to be most closely allied to *Pandora glacialis* Leach which is of a more northern distribution. The latter lacks the more or less distinct radial and somewhat carinate ridges of the left valve. The anterior lateral laminar tooth of the left valve in *inflata* has an excavated area above it whereas in *glacialis* this tooth appears to be flush with the anterior dorsal margin of the hinge line and the excavated area, if at all present, is very much reduced. The swollen convexity of the left valve of *inflata* also is distinct from the more oblate convexity of *glacialis*. The right valve of *glacialis* may be somewhat convex whereas in *inflata* it is somewhat concave.

*Pandora inflata* may be confused with *P. arenosa* but it may be differentiated by its lack of posterior rostration, distinct division of the anterior margin and the ventral margin caused by the anterior radial sulcus and its radial carinate ridges in the left valve. These ridges in *arenosa* tend to be curvilinear whereas in *inflata* they are straight. The anterior sulcus is dorso-ventral in *arenosa* while it is somewhat oblique in *inflata*.

In the Eastern Pacific, *Pandora bilirata* Carpenter and *P. convexa* Dall seem most similar to *inflata*. From *bilirata*, which is probably more closely allied, *inflata* may be distinguished by its more pellucid, subtransparent shell and its greater inflation. *Pandora convexa* is a larger species with a rostrate posterior end, which is lacking in *inflata*.

There does not seem to be a record for *Pandora inflata* in Tertiary deposits in North America.

*Range. Pandora inflata* occurs from the latitude of Sandy Hook, New Jersey, south along the east coast and both sides of Florida. It has been found living in depths between 26 and 90 fathoms and appears to be most populous in the Straits of Florida.

*Specimens examined.* New Jersey: *Delaware*, Station 2–1, alt. tow 50, 126 miles E of Sandy Hook (40°16′ N; 71°22′ W), in 46 fathoms (live) (MCZ); *Albatross* I, Station 2242, 160 miles E of Manasquan Inlet (40°15′ N; 70°27′ W), in 58 fathoms; *Fish Hawk*, Station 920, 150 miles E of Manasquan Inlet (40°13′ N; 70°41′ W), in 63 fathoms; *Albatross* I, Station 2248, 190 miles E of Manasquan Inlet (40°07′ N; 69°57′ W), in 67 fathoms (all USNM); *Delaware*, Station 3–2, alt. tow 31, 73 miles E of Atlantic City (39°20′ N; 72°52′ W), in 40 fathoms (live); *Delaware*, Station 3, tow 5, 101 miles E of Cape May (39°00′ N; 72°48′ W), in 80 fathoms (live) (both MCZ). Virginia: *Albatross* I, Station 2265, 65 miles E of Cape Henry (37°07′ N; 74°35′ W), in 70 fathoms (USNM). North Carolina: *Albatross* I, Station 2268, 20 miles ESE of Cape Hatteras (35°10′ N; 75°06′ W), in 68 fathoms; *Albatross* I, Station 2612, 30 miles SSE of Cape Lookout (34°11′ N; 76°10′ W), in 52 fathoms (all USNM). Florida: Lake Worth (McGinty) (live); off Palm Beach in 130 fathoms; off S. Palm Beach in 75 fathoms (McGinty) (all MCZ); *Eolis*, Stations off Miami, in 24–60 fathoms; *Eolis*, Stations off Government Cut, Miami, in 25–90 fathoms; *Eolis*, Stations off Fowey Light, in 28–125 fathoms; *Eolis*, Station 189, off Cape Florida, in 67 fathoms (live); *Albatross* I, Station 2646–8, off Cape Florida (25°47′ N; 80°05′ W), in 84–85 fathoms; *Eolis*, Stations off Ragged Key, in 65–90 fathoms; *Eolis*, Station 350, off Triumph Reef, in 70–90 fathoms (live); *Eolis*, Stations off Ajax Reef, in 40–100 fathoms; *Eolis*, Station 376, off Caesars Creek, in 90 fathoms (live); *Eolis*, Station 58, off Turtle Harbor, in 50 fathoms (all USNM); NNE off Carysfort Light, in 100 fathoms (live) (MCZ); *Eolis*, Station 45, Lower Matecumbe Key (shore drift); *Eolis*, Station 145, off Long Reef, in 40 fathoms (both USNM); 6 miles SE of Sombrero Light, in 66 fathoms (live); ½ mile SSE of Looe Key, in 29 fathoms (both MCZ); *Eolis*, Stations off Sambo Key, in 50–75 fathoms; *Albatross* I, Station 2315, off Key West (24°26′ N; 81°48′ W), in 37 fathoms; *Eolis*, Stations off Key West, in 55–63 fathoms; *Eolis*, Stations off Sand Key, in 58–62 fathoms; *Eolis*, Station off Dry Tortugas, in 16 fathoms; *Albatross* I, Station 2369, off Cape San Blas (29°16′ N; 85°32′ W), in 26 fathoms (live) (all USNM).

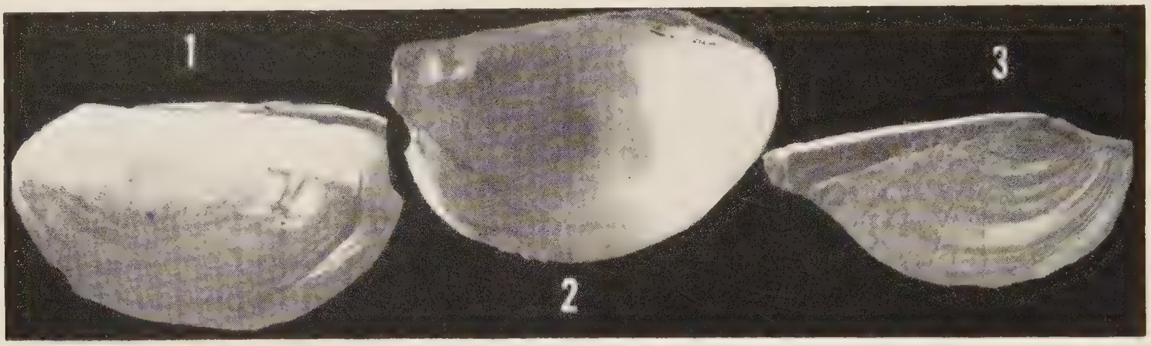

Plate 125. Fig. 1. *Kennerlia brevis* Verrill and Bush 1898, *non* Sowerby 1829 [=*Pandora* (*Pandorella*) *inflata*, new name]. External view of the left valve of the holotype, USNM 40232, *Albatross* I, Station 2248, S of Nantucket, Massachusetts, in 67 fathoms (about 5.7x). Fig. 2. *Pandora* (*Pandorella*) *inflata*, new name. Internal view of the left valve. USNM 323233, *Albatross* I, Station 2369, off Cape San Blas, Florida, Gulf of Mexico, in 26 fathoms (about 4.6x). Fig. 3. *Pandora carolinensis* Bush 1885 [=*Pandora* (*Pandorella*) *arenosa* Conrad 1834]. External view of the right valve of the holotype. USNM 35701, *Albatross* I, Station 2113, off Cape Hatteras, North Carolina, in 15 fathoms (about 3.6x).

## Pandora (Pandorella) glacialis *Leach*

Plate 122, figs. 3–4; Plate 126, figs. 1–4

*Pandora glacialis* Leach 1819 (June), Journal de Physique **88:** 465; 1819 (July), [in] Ross. Voyage of Discovery . . . Baffin's Bay, 2nd Ed., Appx. 4, p. 174: 1819 (Sept.), Annals of Philosophy **14:** 203–204 (Baffin's Bay . . . Spitzbergen, here restricted to Baffin's Bay; syntypes, BMNH, Reg. No. 196273).

*Pandora* (*Kennerlia*) *glacialis* Leach. Carpenter 1864, Proc. Zool. Soc. London, p. 603.

*Kennerlia glacialis* Leach. Bush 1883, Proc. United States Nat. Mus. **6:** 245, figs. 1–1a.

*Pandora* (*Kennerlyia*) *glacialis* Leach. Dall 1915, Proc. United States Nat. Mus. **49:** 448.

*Pandora* (*Kennerlyia*) *glacialis* var. *eutaenia* Dall 1915, Proc. United States Nat. Mus. **49:** 449 (Sitka Harbor, Alaska, in 15 fathoms; syntypes, USNM 171062).

*Pandora* (*Kennerlyia*) *glacialis* Leach. Oldroyd 1924, Marine Shells West Coast North America **1:** 89, pl. 15, fig. 11 and pl. 42, figs. 3–4.

*Pandora* (*Kennerleya*) *glacialis* Leach. Lamy 1924, Jour. de Conchy. **78:** 112.

*Pandora* (*Kennerleya*) *glacialis* var. *eutaenia* Dall. Lamy 1924, Jour. de Conchy. **78:** 113.

*Pandora* (*Kennerlia*) *glacialis glacialis* Leach. LaRocque 1959, Catalogue Rec. Moll. Canada, Nat. Mus. Ottawa, Bull. **129:** 44.

*Pandora* (*Kennerlia*) *glacialis eutaenia* Dall. LaRocque 1959, Catalogue Rec. Moll. Canada, Nat. Mus. Canada, Ottawa, Bull. **129:** 44.

*Description.* Shell extending to 22 mm. in length (about $\frac{7}{8}$ inch) and to 19 mm. in height (about $\frac{3}{4}$ inch), elongate, thin and rather fragile, inequilateral, markedly inequivalve with the left valve convex and centrally inflated and the right valve centrally flattened and sharply concave ventrally; the right valve overlaps the left valve dorsally along the posterior dorsal margin. Umbos anterior, about one-third the total length from the anterior margin, blunt and generally eroded. Anterior margin narrowly rounded, uniting in an indentation with the ventral margin at the anterior radial sulcus; ventral margin broadly rounded, convex and uniting smoothly with the undifferentiated posterior margin, forming a rounded posterior end. Anterior dorsal margin short, nearly straight to slightly convex; posterior dorsal margin long and straight to weakly concave. Left valve with a weak anterior radial sulcus, sharply delimiting the confluence of the anterior margin with the ventral posterior ridge or sulcus lacking so that the umbonal inflation is smooth. Right valve with a weak single posterior radial ridge along the posterior dorsal margin where the overlap with the left valve occurs. Concentric sculpture closely spaced, generally worn away; radial lines evident on the right valve. Hinge with a lithodesma and internal resilium. Dentition of the right valve consists of a long posterior laminate cardinal tooth, a central subtrigonal pedunculate cardinal tooth and an obsolete (or completely absent) anterior cardinal tooth; an extensive external ligament along the anterior dorsal margin present. Dentition of the left valve with a thickened anterior cardinal tooth coextensive with the anterior dorsal margin; weak central cardinal tooth; posterior cardinal tooth formed by a thickening along the posterior dorsal margin. Adductor muscle scars impressed, particularly the anterior scar in the right valve; pallial line consists of irregularly arranged individual scars. Shell white, shining internally, chalky and eroded externally; erosion often reveals the nacreous layer of the left valve externally; periostracum thickened and dull dirty white.

| length | height | width | |
|---|---|---|---|
| 21.2 mm. | 13.5 mm. | 3.8 mm. | Between Cape Mugford and Hebron, Labrador, in 60 fathoms |
| 20.6 | 11.0 | 3.8 | Bight, Shannon Island, N.E. Greenland |
| 12.8 | 7.9 | 2.6 | King Francis Joseph Fjord, N.E. Greenland |
| 12.1 | 7.4 | 2.3 | Collingham's Cove, Hamilton Inlet, Labrador, in 7 fathoms |
| 9.4 | 5.3 | 1.5 | Grande Creve, Gaspé, Quebec, in 20–40 fathoms |

*Remarks.* In the Western Atlantic, *Pandora glacialis* stands more or less widely separated from other *Pandora*. It is distinguished by its left anterior cardinal tooth which is coalesced with the anterior dorsal margin of the shell. There does not appear to be an excavated cavity dorsal to this tooth. Verrill (1881) identified some specimens as *glacialis* which later proved to be a new species, *Pandora brevis* Verrill and Bush (*non* Sowerby) (= *P. inflata*), which may be confused with *glacialis*. The presence of a carinate ridge and the swollen ventral portion of the left valve of *inflata* immediately separates it from *glacialis*.

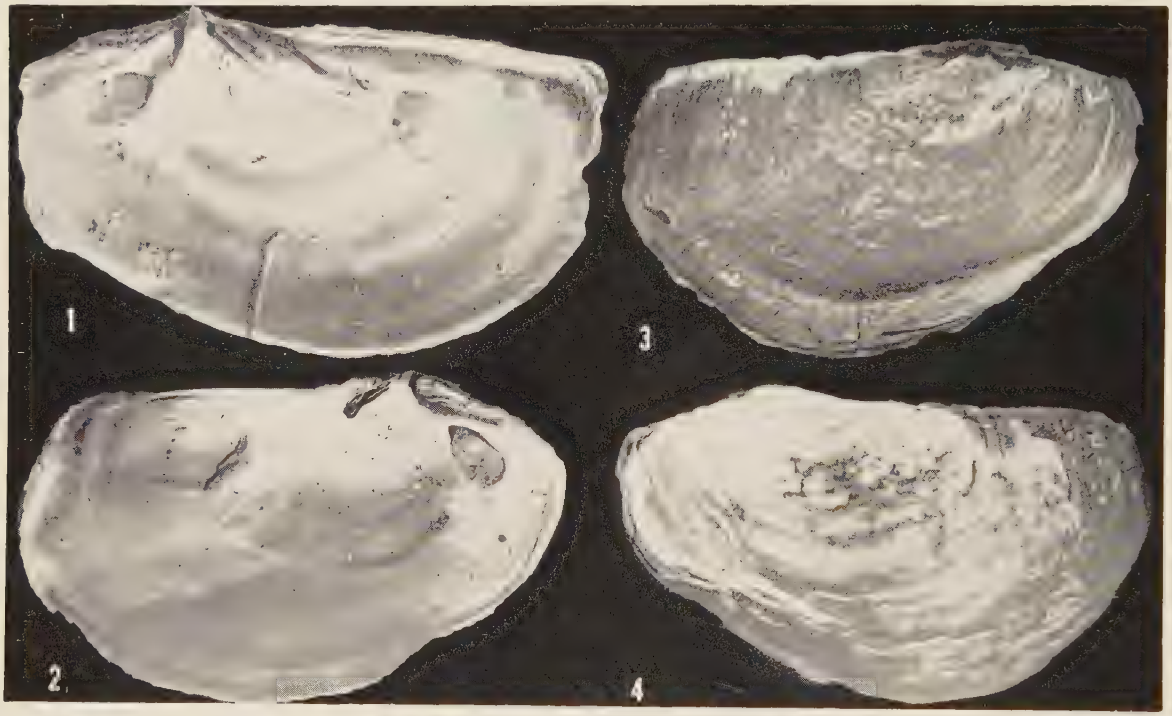

Plate 126. Figs. 1–4. *Pandora* (*Pandorella*) *glacialis* Leach 1819. Figs. 1 and 2. USNM 444667, between Cape Mugford and Hebron, Labrador. Specimens sprayed with ammonium chloride vapor. Fig. 1. Internal view of the right valve (about 3.9x). Fig. 2. Internal view of the left valve (about 3.3x). Figs. 3 and 4. USNM 50680, *Albatross* I, Station 2499, N of Sable Island, in 130 fathoms. Fig. 3. External view of the right valve (about 2.9x). Fig. 4. External view of the left valve (about 3x).

Ockelmann (1958) has reported that *glacialis* is a member of the *Gomphia fluctuosa* community in East Greenland, occurring at depths between 3 and 10 fathoms on sandy bottoms near the open sea. The species is hermaphroditic (Thorson, 1936), and Ockelmann has indicated that spawning takes place later than mid-August in East Greenland and that the larval development is lecithotrophic with a pelagic stage which is either very short or entirely lacking. It appears that *glacialis* is a filter feeder and Odhner (1915) has recorded the presence of mud and plankton in the alimentary canal.

An amphipod, *Metopa groenlandica* Hansen, has been reported attached to the ctenidia of specimens of *glacialis* collected in East Greenland (Stephensen and Thorson, 1936).

From samples of living populations, the depth range of this species is between 3 and 130 fathoms. As Clarke (1962) has pointed out, Gorbunov's record (1946) of 1040 fathoms represents a dead specimen which occurred advectitiously at this great depth. Soft bottom types, including mud, sand, and muddy sand are preferred by *glacialis*.

Some ecological factors must contribute to the peculiarly large specimens of this species along the Alaskan coast from Prince Williams Sound to Sitka, for samples from this area are larger and somewhat more rostrate posteriorly. For these populations, Dall (1915) established the varietal name *eutaenia* which is included in the synonymy.

This species has been found fossil in the Pliocene of California in the Pico formation near Ventura (Waterfall, 1929). *Pandora arctica* Dall of the Leda Clays of Saco, Maine and of St. John, New Brunswick appears to be an immediate precursor of *glacialis*. Richards (1962) has listed the Pleistocene deposits in which *glacialis* has been found. Feyling-Hanssen (1955) has recorded *glacialis* in the late Pleistocene of West Spitzbergen.

*Range.* *Pandora glacialis* is predominantly high arctic and circumpolar in its distribution; however, it extends to lower latitudes on both coasts of North America. It is normally found as far south as the Gulf of St. Lawrence on the Atlantic coast and Vancouver Island and the Straits of Juan de Fuca, British Columbia, on the Pacific coast. The species inhabits the Arctic coasts of Canada, Alaska, the Soviet Union and Scandinavia. It has been found in numerous localities in East Greenland (Ockelmann, 1958), but is not known from West Greenland or Iceland. Odhner (1915) gives an extended list of records with references to citations in European literature. The species has been taken alive in depths to 130 fathoms.

*Specimens examined.* Arctic Ocean: Matochkin Shar (=strait), Novaya Zemblya, in 5 6 fathoms; U.S.S. *Corwin*, north of Bering Strait; off Icy Cape, Alaska, in 17 fathoms; off Cape Sabine, Alaska, in 13 fathoms; off Point Belcher, Alaska, in 9 fathoms (all USNM). Bering Sea: U.S.S. *Corwin*, in Bering Straits, in 30 fathoms; north end of Nunivak Island, Alaska, in 9 fathoms; *Albatross* I, Station 3554, off Pribiloff Island (56°34′ N; 170°19′ W), in 62 fathoms (all USNM). North Pacific Ocean: Port Etches, Hinchinbrook Island, in 15 fathoms; Port Mulgrave, Yakutat Bay, in 30 fathoms; Lituya Bay, in 8 fathoms; Sitka Harbor, in 12–15 fathoms; Victoria, Vancouver Island, in 65 fathoms (all USNM). Greenland: Bight, Shannon Island (live); Cape Stosch, Godthaabs Gulf, in 7 fathoms; King Franz Joseph Fjord (live) (all USNM). Labrador: Halfway between Cape Mugford and Hebron, in 60 fathoms (live); Collingham's Cove, Hamilton Inlet, in 7 fathoms (live) (both USNM). Quebec: Grand Greve, Gaspé, in 20 40 fathoms (live) (USNM). Newfoundland: *Albatross* I, Station 2458, off SE Newfoundland (46°48′ N; 52°34′ W), in 89 fathoms (USNM). Nova Scotia: *Albatross* I, Station 2499, N of Sable Island (44°46′ N; 59°55′ W), in 130 fathoms (live) (USNM); East of Cape Sable, in 55 fathoms (MCZ). Massachusetts: Liberty Street, Danvers (live) (MCZ).

* * * *

## *Notes*

The existence of species of *Pandora* along the Atlantic Coast of South America is difficult to document. At least two specific names have been used in the South American literature.

*Pandora braziliensis* 'Gould ms' Sowerby 1874 [in] Reeve, Conchologica Iconica **19**: *Pandora*, pl. 2, fig. 15.

*Pandora cistula* Gould 1850. Proc. Boston Soc. Nat. Hist. **3: 217**; 1852. United States Explor. Exped., Moll., p. 396, pl. 33, figs. 500–500b.

No specimens of any pandorid from South America were available to the authors at the time of this study and therefore neither of the above have been treated systematically in the text.

* * * *

## BIBLIOGRAPHY

Allen, J.A. 1954. On the structure and adaptations of *Pandora inaequivalvis* and *P. pinna*. Quart. Jour. Micro. Sci. **94**(4): 473–482.

Allen, J.A. 1961. Development of *Pandora inaequivalvis* Linné. Jour. Embryol. Exp. Morphol. **9:** 252–268.

Allen, M.P. and J.A. 1955. On the habits of *Pandora inaequivalvis* Linné. Proc. Malac. Soc. London **31:** 175–185.

Apgar, A.C. 1891. Mollusks of the Atlantic coast of the United States south to Cape Hatteras. Jour. New Jersey Nat. Hist. Soc. **2:** 75–162.

Arvy, L. and J.M. Gaillard. 1956. Castration parasitaire de *Pandora albida* (Röding), *P. inaequivalvis* L., mollusque pelecypode eulamellibranche par *Cercaria melanocystea* n. sp. cercaire à grande queue resiculeuse. C.R. Acad. Sci., Paris **243:** 1074–1077, 3 figs.

Atkins, D. 1937. On the ciliary mechanism and interrelationships of lamellibranchs. Pt. 2. Quart. Jour. Micro. Sci. **79:** 379–421.

Blake, S.F. 1953. The Pleistocene fauna of Wailes Bluff and Langley Bluff, Maryland. Smithsonian Misc. Coll. **121**(12): 32 pp.

Burne, R.H. 1920. Mollusca. Pt. IV. Anatomy of Pelecypoda. British Antarctic Expedition (Terra Nova), Zool. II, no. 10, pp. 233–256, pls. 1–4.

Carpenter, W. 1848. Report on microscopic structure of shells. Report Brit. Assoc. Ad. Sci. [for 1847], pp. 93–134, pls. 1–20.

Chemnitz, J.H. 1795. [in] Martini-Chemnitz. Neues systematisches Conchylien-Cabinet **11:** 211.

Children, J.G. 1823. Lamarck's Genera of Shells. Quart. Jour. Sci., Lit., and Arts **14:** 301.

Clarke, A.H. Jr. 1962. Annotated list and bibliography of the abyssal marine mollusks of the world. Nat. Mus. Canada, Bull. 181, 114 pp.

Cossmann, A.E.M. 1886. Catalogue des coquilles fossiles d'Éocène des environs de Paris. Pelecypodes. Ann. Soc. Roy. Malac. Belgique **21**(4th Ser., vol. 1): 17–186, pls. 1–8.

Dall, W.H. 1886. Reports on the results of dredging, under the supervision of Alexander Agassiz, in the Gulf of Mexico (1877–78) and in the Caribbean Sea (1879–80), by the U.S. Coast Survey steamer "Blake", Lieut. Commander C.D. Sigsbee, U.S.N. and Commander J.R. Bartlett, U.S.N. commanding.

XXIX. Report on the Mollusca. Part 1. Brachiopoda and Pelecypoda. Bull. Mus. Comp. Zool. **12**(6): 171–318, 19 pls.

Dall, W.H. 1889. A preliminary catalogue of the shell-bearing marine mollusks and brachiopods of the southeastern coast of the United States with illustrations of many of the species. U.S. Nat. Mus., Bull. 37, 221 pp., 74 pls.

Dall, W.H. 1903. Tertiary fauna of Florida. Transactions of the Wagner Free Institute of Science of Philadelphia **3**(6): 1515–1522.

Dall, W.H. 1915. A review of some bivalve shells of the group Anatinacea from the west coast of America. Proc. U.S. Nat. Mus. **49:** 441–456.

Deshayes, G.P. 1848. Histoire naturelle des Mollusques. Mollusques Acephales. Exploration scientifique de l'Algerie, pp. 240–260, Paris.

Deshayes, G.P. 1860. Description . . . animaux sans vertébres. Mollusques Acephales Dimyaires. Paris **1:** 912 pp., 89 pls.

Dodge, H. 1947. The Molluscan genera of Bruguière. Jour. Paleo. **21**(5): 484–492.

Duvernoy, M. 1853. Mémoires sur le systéme nerveux des Mollusques Acephales. Mém. Acad. Sci., Paris **24:** 3–312.

Feyling-Hanssen, R.W. 1955. Stratigraphy of the marine Late-Pleistocene of Billefjordan, Vestspitsbergen. Skrifter norsk Polarinst. **107:** 1–186, 27 pls., 57 figs.

Gardner, J. 1943. Mollusca from the Miocene and Lower Pliocene of Virginia and North Carolina. Pt. 1. Pelecypoda U.S. Geol. Sur., Prof. Paper 199-A, 178 pp., 23 pls.

Gorbunov, C.P. 1946. Bottom life of the Novosiberian shoalwaters and the central part of the Arctic Ocean. Dreifuiushchaia ekspeditsiia Glavseomorputi na ledokol' nom parokhodi 'G. Sedov', 1937–1940. g.g. Trudy **3:** 30–138. [Not seen by the authors.]

Gould, A.A. 1841. A report on the Invertebrata of Massachusetts. Cambridge, 373 pp.

Grant, U.S. IV, and H.S. Gale. 1931. Catalogue of the marine Pliocene and Pleistocene Mollusca of California. Memoirs San Diego Soc. Nat. Hist. **1:** 1,036 pp., 32 pls.

Gray, J.E. 1847. A list of the genera of recent Mollusca, their synonyms and types. Proc. Zool. Soc. London **15:** 129–219.

Hertlein, L.G. and A.M. Strong. 1946. Eastern Pacific Expeditions of the New York Zoological Society. 35. Mollusks from the west coast of Mexico and Central America. Pt. IV. Zoologica **31**(3): 93–120, 1 pl.

Jacot, A.P. 1921. Some marine molluscan shells of Beaufort and vicinity. Jour. Elisha Mitchell Sci. Soc. **36:** 129–145, pls. 11–13.

Keen, A.M. 1958. Sea shells of tropical west America. Stanford Univ. Press, 624 pp., 1709 figs., 10 color pls.

Kobelt, W. 1878. Illustriertes conchylienbuch. Nürnberg, 391 pp.

Lacaze-Duthiers, F.J.H. 1854. Recherches sur les organes genitaux des Acephales Lamellibranches. Ann. Sci. Nat., 4th Ser., Zool. **3:** 155–248, pls. 5–9.

Ladd, H.S. 1951. Brackish-water and marine assemblages of the Texas coast, with special reference to Mollusks. Publ. Inst. Marine Sci. **2**(1): 125–164.

Lamarck, J.B.P.A.M. 1799. Prodrome d'une nouvelle classification des coquilles. Mem. Soc. Hist. Nat. Paris, pp. 63–90.

Maury, C.J. 1920. Recent molluscs of the Gulf of Mexico and Pleistocene and Pliocene species from the Gulf States. Pelecypoda. Pt. 1. Bull. Amer. Paleo. **8**(34): 3–115, 1 pl.

Menegaux, A. 1890. Recherches sur la circulation des Lamellibranches marins. Besancon, 296 pp.

Morse, E.S. 1919. Observations on living lamellibranchs of New England. Proc. Boston Soc. Nat. Hist. **35**(5): 139–196.

Ockelmann, W.K. 1958. The Zoology of East Greenland. Marine Lamellibranchiata. Medd. om Grönland **122**(4): 256 pp., 3 pls.

Odhner, N. 1912. Morphologische und phylogenetische Untersuchungen über die Nephridien der Lamellibranchien. Zeits. f. wissen. Zool. **100**(2): 348–350.

Odhner, N. 1915. Die Mollusken des Eisfjordes. Zool. Ergebn. Schwed. Exped. nach Spitzbergen 1908. K. svenska Vetensk. Akad. Handl. **54**(1): 1–274, 13 pls.

Olsson, A.A. 1961. Mollusks of the Tropical Eastern Pacific. Panamic—Pacific Pelecypoda. Paleontological Research Inst., Ithaca, N.Y., 574 pp., 86 pls.

Olsson, A.A. and A. Harbison. 1953. Pliocene Mollusca of southern Florida. Acad. Nat. Sci. Phila., Monograph 8, Pt. 1, 361 pp.

Palmer, K.V.W. 1958. Type specimens of marine mollusca described by P. P. Carpenter from the West Coast (San Diego to British Columbia). Geol. Soc. Amer. Memoir 76, 376 pp., 35 pls.

Parker, R.H. 1956. Macro-invertebrate assemblages as indicators of sedimentary environments in East Mississippi Delta Region. Bull. Amer. Assoc. Pet. Geol. **40**(2): 295–376, 8 pls.

Parker, R.H. 1959. Macro-invertebrate assemblages of central Texas coastal bays and Laguna Madre. Bull. Amer. Assoc. Pet. Geol. **43**(9): 2106–2166.

Parker, R.H. 1960. Ecology and distributional patterns of macro-invertebrates, northern Gulf of Mexico. Recent Sediments, Northwest Gulf of Mexico, 1951–1958. Amer. Assoc. Pet. Geol., Tusla, pp. 302–381.

Pelseneer, P. 1911. Les Lamellibranches de l'Expedition du Siboga. Partie Anatomique. Siboga-Expeditie, Monographie 103 a, 125 pp., 26 pls.

Perkins, G.H. 1869. The molluscan fauna of New Haven. Proc. Boston Soc. Nat. Hist. **13:** 109–163.

Perry, L.M. and J.S. Schwengel. 1955. Marine shells of the western coast of Florida. Paleontological Research Inst., Ithaca, N.Y., 318 pp., 55 pls.

Prashad, B. 1932. Pelecypoda of the Siboga Expedition. Siboga-Expeditie, Monographie 53 c, 353 pp., 9 pls.

Purchon, R.D. 1958. The stomach in the Eulamellibranchia: Stomach Type IV. Proc. Zool. Soc. London **131:** 487–525.

Pulley, T.E. 1952. An illustrated check list of the marine mollusks of Texas. Texas Jour. Sci. **2:** 167–199, 13 pls.

Richards, H.G. 1936. Marine shells of James Bay. Amer. Midl. Nat. **17**(2): 528–545.

Richards, H.G. 1962. Studies of the marine Pleistocene. Pts. 1 & 2. Trans. Amer. Phil. Soc. **52**(3): 1–141.

Ridewood, W.G. 1903. On the structure of the gills of the Lamellibranchia. Phil. Trans. Roy. Soc. London, Ser. B, **195:** 147–284.

Röding, P.F. 1798. Museum Boltenianum. Hamburg, 199 pp.

Schmidt, F.C. 1818. Versuch der Conchylien-Sammlungen. Gotha, 252 pp.

Sherborn, C.D. and B.B. Woodward. 1906. On the dates of publication of the natural history portions of the Encyclopédie Méthodique. Ann. Mag. Nat. Hist., Ser. 7, **17:** 577–582.

Singley, J.A. 1893. Contributions to the natural history of Texas. Pt. 1, Texas Mollusca. Preliminary list of the land, fresh water and marine mollusca of Texas. 4th Ann. Report Geol. Survey Texas, Pts. 1 & 2, pp. 299–343.

Stephensen, K. and G. Thorson. 1936. On the amphipod *Metopa groenlandica* H. J. Hansen found in the mantle cavity of the lamellibranchiate *Pandora glacialis* Leach in East Greenland. Medd. om Grönland **118**(4): 7 pp.

Stewart, R.B. 1930. Gabb's California Cretaceous and Tertiary type lamellibranchs. Acad. Nat. Sci. Phila., Spec. Publ. No. 3, 314 pp., 17 pls.

Stoliczka, F. 1871. Memoirs Geol. Survey India. Palaeontologia Indica. Cretaceous Fauna of southern India **3:** 1–537.

Sullivan, C.M. 1948. Bivalve larvae of Malpeque Bay, Prince Edward Island. Fish. Res. Board Canada. Bull. 77, 36 pp., 22 pls.

Sumner, F.B., R.C. Osburn, and L.J. Cole. 1913. A biological survey of the waters of Woods Hole and vicinity. Part II. Section III. A catalogue of the marine fauna. Bull. U.S. Bur. Fish., 31, Pt. 2, pp. 545–794.

Thorson, G. 1936. The larval development, growth and metabolism of Arctic marine bottom invertebrates. Medd. om Grönland **100**(6): 155 pp.

Verrill, A.E. 1881. Notice of the remarkable marine fauna occupying the outer banks off the southern coast of New England, No. 2. Amer. Jour. Sci., 3 ser. **22:** 292–303.

Vokes, H.E. 1956. Notes on, and rectifications of, pelecypod nomenclature. Jour. Paleo. **30**(3): 762–765.

Warmke, G.L. and R.T. Abbott. 1961. Caribbean Sea-shells. Narberth, Pennsylvania, 346 pp., 44 pls.

Waterfall, L.N. 1929. Univ. California Pub., Bull. Dept. Geol. Sci. **18**(3): 71–92, pls. 5–6.

Winckworth, R. 1934. Names of British Mollusca III. Jour. Conch. **20**(2): 51–53.

Zittel, K.A. von. (trans. by C. R. Eastman). 1900. Text-book of Palaeontology. New York **1:** 390 pp.

## Book Reviews

Gould, A.A. 1841, Report on the Invertebrata of Massachusetts, Cambridge, Mass., pp. xiii + 373, pls. 15. This was the first publication in North America to cover extensively the fauna of a geographic area the size of the State of Massachusetts. All types of mollusks are covered: the land, freshwater and marine forms. A few other Phyla are covered, such as the Crustacea, Annelida and Echinodermata, but not the Insecta. 318 out of 373 pages are devoted to the Mollusca.

The full impact of this volume upon the culture of that period probably will never be fully known. It was a great stimulation to W. H. Dall as a young malacologist as it was to many other scientists. Gould gave a copy to William Stimpson, then only a young man, and this single gift was responsible for his career in the field of malacology.

Gould made all of the 213 beautifully executed figures which were then engraved on copper plates. His descriptions are full and exceedingly clear and understandable.

Gould, A.A., edited by W.G. Binney 1870, Report on the Invertebrata of Massachusetts, Boston, Mass., pp. v + 524, pls. 12 and 405 text figures. The 1841 edition was soon out of print, and in 1865 the Legislature of Massachusetts directed a new and revised edition of this work to be published by Dr. Gould. In 1866, Dr. Gould, with the revision only partially completed, died. In 1867, the Legislature authorized the Governor and Council to appoint some person to complete the work, and W. G. Binney was chosen to do this task. The original copper plates could not be located, so the task fell to E. S. Morse to make a complete set of drawings on wood which composed the text figures. All of the plates but one are in color and these mainly showing nudibranchs and cephalopods. All of the figures on the plates as well as the text figures are numbered, continuing the numbers given in the first edition. The last figure in the first edition was no. 213, the first figure on the first plate in the second edition is no. 214 and ends on the last plate with fig. 349. The text figures start with no. 350 and end with no. 755.

Old as this work is, it still is our standard reference for New England, the names being modernized by C. W. Johnson's "Mollusca of New England" (1915) and his "List of Marine Mollusca of the Atlantic Coast from Labrador to Texas" (1934).

The first edition was concerned mainly with Massachusetts; the second edition was much broader in scope and dealt with nearly all of New England.

—W. J. Clench

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# DEGREE OF HOST SPECIFICITY IN TWO SPECIES OF *ODOSTOMIA* (PYRAMIDELLIDAE: GASTROPODA)

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# DEGREE OF HOST SPECIFICITY IN TWO SPECIES OF *ODOSTOMIA* (PYRAMIDELLIDAE : GASTROPODA)

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(*Read* 12 *March* 1965)

## INTRODUCTION

The genus *Odostomia* is well known as an ectoparasitic gastropod. Pelseneer (1928) gave a long list of species and their hosts. More recently Robertson and Orr (1961) reviewed the known non-molluscan hosts of the genus. Fretter and Graham (1949) established that the pyramidellids possess opisthobranch affinities. In stating that pyramidellids are host-specific, they questioned numerous cases in the early literature documenting non-host specificity in the family. Several recent reports present additional evidence that certain species of *Odostomia* are definitely not host-specific.

The literature contains examples where it is shown that a wide range of hosts may be parasitized, as in *Odostomia scalaris* Macgillivray (Ankel and Christensen, 1963) or *Odostomia* (*Menestho*) *impressa* (Say). In other species the ectoparasite is limited and known, at least presently, only from a single host, as in *O. perezi* Dautzenberg and Fischer (Gardiner, 1934; Ockelmann *in* Ankel and Christensen, 1963) and *O. dianthophila* Wells and Wells (Wells and Wells, 1961) or *O. chitonicola* Smith (Smith, 1899; Robertson and Orr, 1961).

*Odostomia* (*Chrysallida*) *seminuda* (C. B. Adams—Plate 15, No. 1—and *Odostomia* (*Menestho*) *bisuturalis* (Say)*—Plate 15, No. 2—were considered in this study. Adams (1839) and Hackney (1944) noted that *O. seminuda* was a parasite of *Aequipecten* (*Plagioctenium*) *irradians* (Lamarck); Robertson (1957) pointed to another host for this same parasite, namely *Crepidula fornicata* (Linnaeus), and Wells and Wells (1961) included *Aequipecten* (*Plagioctenium*) *gibbus* (Linnaeus) in the list of known hosts for *seminuda.* For *O. bisuturalis,* Pelseneer (1928) recorded it as associated with *Modiolus plicatulus* Lamarck [=*Modiolus* (*Brachidontes*) *demissus* Dillwyn], Loosanoff (1956) described its parasitic behaviour on *Crassostrea virginica* (Gmelin), and Allen (1954) reported *O. bisuturalis* from Maryland and found later (1958) that

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*Our specimens of *bisuturalis* have highly variable shell sculpture as regards the number and strength of sutural cords. We have illustrated a specimen with average shell characters.

in the local populations, *O. bisuturalis* appeared not to be parasitic by rejecting a number of experimental animals, including oysters. Some authors (Laseron, 1951; Sanders, 1958) have proposed that certain species are not at all associated with hosts but are free living organisms which feed on bottom materials. Robertson and Orr (1961) and others suggest, however, that the feeding apparatus of the pyramidellids is such that they have no alternative but to feed in a parasitic manner.

We propose to show that two species of *Odostomia* actively shift from one host to another and in the process spend much of their time on the bottom. Further, we want to point out that, on the basis of cumulative evidence concerning the ectoparasites used in this study, it is probable that each species of *Odostomia* possesses a selective range of host species as well as an order of host preference.

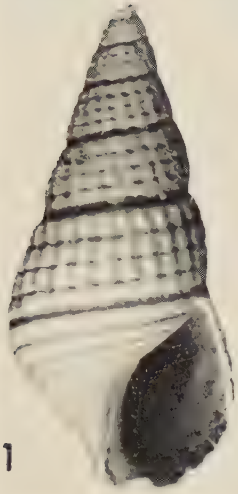
## COLLECTION LOCALITIES

Specimens of *Odostomia seminuda* and *O. bisuturalis* for the present study came from Bass River, an estuarine habitat near West Dennis, Massachusetts. *Odostomia seminuda* was taken at the mouth of Bass River on *Crepidula fornicata* in shallow water not more than 1 m deep at low tide. Specimens of *bisuturalis* were taken on *Crassostrea virginica* in a shallow bay near the mouth of the river. Not all specimens, however, were taken from host animals; some were on the shell remains of dead oysters.

A number of molluscs were chosen as possible hosts for the *Odostomia*. These experimental animals came either from inshore localities in the vicinity of Woods Hole, Massachusetts, with the exception of the host animals from Bass River, or from offshore in Great South Channel, Nantucket Shoals (lat. 40°37′ N; long. 69°08′ W) in 37 fathoms. The offshore species, indicated by an asterisk in the list that follows, are abiotopic with respect to the natural habitat of both *O. bisuturalis* and *O. seminuda*. The species selected were: **Crucibulum* (*Dispotaea*) *striatum* Say, *Crepidula fornicata*, **Crepidula plana* Say, **Arctica islandica* (Linnaeus), *Mercenaria mercenaria* (Linnaeus), **Placopecten magellanicus* (Gmelin), *Aequipecten irradians*, **Modiolus modiolus* (Linnaeus) and *Crassostrea virginica*. Representatives of each species have been preserved in the United States National Museum, Washington.

## PROCEDURE

The experiments were carried out in the Bureau of Commercial Fisheries Biological Laboratory in Woods Hole, Massachusetts, during the summer of 1963. The specimens of *Odostomia* collected in the field were placed in holding tanks together with host specimens and allowed to condition about 2 weeks before the experiments began. 'Large' and 'small' glass containers, about 12 and 3 in. in diameter and 2½ and 1½ in. deep, respectively, were used for individual experiments within a water tray, 18 × 24 × 3 in. The water tray in turn was in a larger tank, 28 × 52 × 6 in., with a continuous supply of running sea water. It was discovered in the early trials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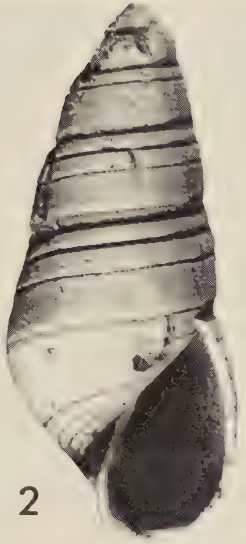
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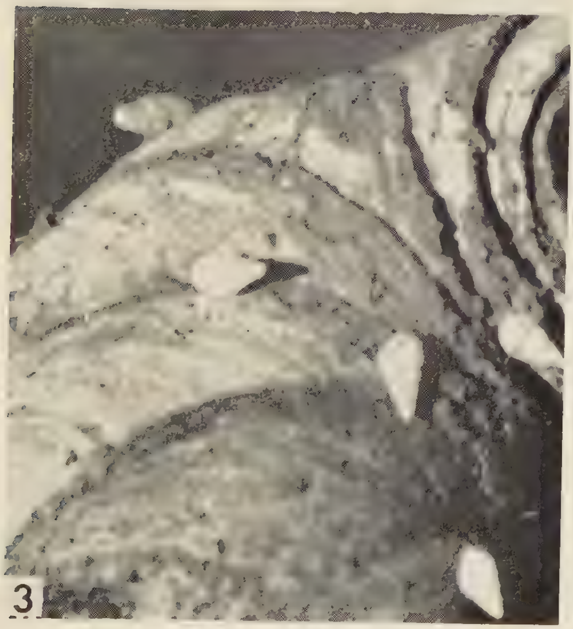
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No. 1. *Odostomia* (*Chrysallida*) *seminuda* (C. B. Adams). Actual height of specimen, 3·7 mm.

No. 2. *Odostomia* (*Menestho*) *bisuturalis* (Say). Actual height of specimen, 4·0 mm.

No. 3. *Odostomia seminuda* in natural feeding position at the edges of individual specimens in an aggregate of *Crepidula fornicata* (Linnaeus).

that a double, small screen (1.2 mm mesh) placed over the containers and water tray was necessary to keep the *Odostomia* from escaping. For its size *Odostomia* can travel over considerable territory within a relatively short time. One traversed 12 in. in 30 min. Without the screen, they escaped to the larger tank and wandered into containers housing separate experiments. In all the experiments, the substrate upon which the snails settled was glass.

The feeding habits of *Odostomia* are such that they crawl to the external periphery of a host's shell where they are in position to extend the proboscis and penetrate host tissue (Merrill and Boss, 1964). In recording the results of experiments, specimens of *Odostomia* were said to be on the host when they were in feeding position, that is, no less than $\frac{1}{8}$ in. from the edge of the mantle of the host (Plate 15, No. 3). Hosts were offered under different experimental conditions as recorded later.

## EXPERIMENTS ON HOST–PARASITE RELATIONS

### *Relation between the two ectoparasites and their original hosts*

Preliminary experiments with the two species of *Odostomia* and the host species on which they were collected were designed to determine if the ectoparasites would exchange hosts. An additional objective was to discover if the animals deserted their hosts and wandered about the substrate. Initially fifty-eight *Odostomia seminuda* and eighteen *O. bisuturalis,* together with a number of their respective hosts, were placed at random in a large water tray and left undisturbed. After 2 weeks, forty specimens of *O. seminuda* were found in the feeding position on *Crepidula fornicata,* their original host, and eighteen specimens were wandering on the substrate. Only three *O. bisuturalis* were on their original host, *Crassostrea virginica,* the remaining thirteen were on the substrate. Neither species of *Odostomia* was found on the opposite host in this experiment.

In another experiment, both species of *Odostomia* were placed in small glass containers at opposite ends of the water tray and each was surrounded by specimens of the opposite host. Thus, to reach its original host, each ectoparasite had to crawl out of the small container, by-pass the opposite host and travel the entire length of the tray. The experiment was terminated 2 days later. Of thirty *O. seminuda,* twenty-four were found with *Crepidula fornicata,* two with *Crassostrea virginica* and four were on the substrate; of twelve *O. bisuturalis,* two were found with *Crassostrea virginica,* two with *Crepidula fornicata* and eight were on the substrate. It was evident that the species of *Odostomia* may associate with opposite hosts.

In another series of experiments with the ectoparasites and their original hosts, the species were arranged together in several small glass containers in the water tray. After 2 days, the relative positions of the ectoparasites were noted. The experiment was repeated four times and the general results are tabulated in Table 1. Here it is seen that each parasite preferred its original host but that one was found occasionally on the opposite host. It is evident also that both *O. seminuda* and *O. bisuturalis* spend a considerable amount of time on the substrate.

The general results of these preliminary experiments reveal that the ectoparasites

Table 1. Results of an experiment (four trials) showing incidence of occurrence of *Odostomia seminuda* and *O. bisuturalis* either in feeding position on hosts or on the substrate. The ectoparasites were given a choice of the hosts on which they were originally collected

| Ectoparasites found on | Total incidence | |
|---|---|---|
| | *O. seminuda* | *O. bisuturalis* |
| *Crepidula fornicata* | 106 | 5 |
| *Crassostrea virginica* | 15 | 18 |
| Substrate | 40 | 15 |

prefer their original hosts but that they will exchange hosts. It was determined also that parasites are not always in feeding position; in fact, on the average, over one-third of the animals were on the glass substrate at the termination of the experiments.

*Relation between the ectoparasites and selected hosts*

To determine the possible hosts for both species and to discover which hosts were the most desirable, both *O. seminuda* and *O. bisuturalis* were placed together in large glass containers in the water tray along with a variety of different hosts. One of these experiments included trials with the quahog, *Mercenaria mercenaria,* and the bay scallop, *Aequipecten irradians,* individually. Five trials with *M. mercenaria* proved that *O. seminuda* and *O. bisuturalis* attacked the host only infrequently. Both *O. seminuda* and *O. bisuturalis* attacked *A. irradians,* but *O. bisuturalis* markedly preferred it.

Table 2. Results of an experiment (five trials) showing number of times *Odostomia seminuda* and *O. bisuturalis* were taken either in feeding position on three gastropod hosts or on the substrate

| Ectoparasites found on | Total incidence | |
|---|---|---|
| | *O. seminuda* | *O. bisuturalis* |
| *Crepidula fornicata* | 15 | 1 |
| *Crepidula plana* | 0 | 0 |
| *Crucibulum striatum* | 18 | 6 |
| Substrate | 4 | 14 |

Tests of the parasites with the three species, *Crepidula fornicata, C. plana,* and *Crucibulum striatum,* demonstrated that neither of the parasites was attracted to *plana* (Table 2), but that *striatum* and *fornicata* were equally attractive to *O. seminuda. Odostomia bisuturalis* went to *Crucibulum striatum* but was found more often on the bottom. The fact that *C. striatum* should be a choice host for both ectoparasites is curious, because the species inhabit different biotopes and rarely, if ever, come into contact in nature (Merrill and Boss, 1964).

Both ectoparasites were exposed to numerous hosts in still another experiment (Table 3). In the seven trials which constituted the experiment, the original hosts, *Crepidula fornicata* and *Crassostrea virginica,* as well as *Mercenaria mercenaria,*

Table 3. Results of an experiment (seven trials) showing incidence of occurrence of *Odostomia seminuda* (S) and *O. bisuturalis* (B) either in feeding position on a variety of hosts or on the substrate

| Ectoparasites found on | Trial 1 |  | Trial 2 |  | Trial 3 |  | Trial 4 |  | Trial 5 |  | Trial 6 |  | Trial 7 |  | Total incidence |  |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
|  | S | B | S | B | S | B | S | B | S | B | S | B | S | B | S | B |
| *Crepidula fornicata* | 18 | 3 | 16 | 0 | 16 | 0 | 22 | 0 | 12 | 0 | 17 | 0 | 4 | 0 | 105 | 3 |
| *Mercenaria mercenaria* | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 |
| *Crassostrea virginica* | 2 | 5 | 1 | 7 | 1 | 5 | 1 | 0 | 0 | 2 | 0 | 0 | 1 | 1 | 6 | 20 |
| *Modiolus modiolus* | 1 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 1 | 3 | 2 |
| *Aequipecten irradians* | 0 | 1 | 0 | 0 | 3 | 6 | 0 | 3 | 6 | 4 | 2 | 4 | 1 | 4 | 12 | 22 |
| Substrate | 0 | 3 | 3 | 5 | 0 | 0 | 0 | 2 | 4 | 6 | 5 | 2 | 16 | 0 | 28 | 18 |

Table 4. Results of an experiment (eight trials) showing incidence of occurrence of *Odostomia seminuda* (S) and *O. bisuturalis* (B) either in feeding position on a selection of hosts or on the substrate

| Ectoparasites found on | Trial 1 |  | Trial 2 |  | Trial 3 |  | Trial 4 |  | Trial 5 |  | Trial 6 |  | Trial 7 |  | Trial 8 |  |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
|  | S | B | S | B | S | B | S | B | S | B | S | B | S | B | S | B |
| *Crepidula fornicata* | 3 | 1 | 5 | 0 | – | – | – | – | – | – | 7 | 1 | 10 | 1 | 7 | 1 |
| *Mercenaria mercenaria* | 3 | 0 | – | – | 2 | 0 | 2 | 0 | – | – | – | – | – | – | – | – |
| *Modiolus modiolus* | 0 | 0 | 1 | 0 | 3 | 0 | 5 | 0 | 1 | 1 | – | – | – | – | – | – |
| *Aequipecten irradians* | 6 | 5 | 2 | 2 | 3 | 5 | 8 | 7 | 14 | 18 | 15 | 18 | 5 | 6 | – | – |
| *Crucibulum striatum* | 3 | 0 | 5 | 1 | 1 | 0 | 3 | 1 | 9 | 1 | 3 | 1 | – | – | 15 | 6 |
| *Crepidula plana* | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 1 | 0 | 0 | – | – | – | – | 0 | 0 |
| *Crassostrea virginica* | – | – | 0 | 1 | 0 | 1 | 1 | 0 | 0 | 0 | – | – | 2 | 0 | – | – |
| *Artica islandica* | – | – | – | – | 0 | 0 | 0 | 0 | 0 | 0 | – | – | – | – | – | – |
| *Placopecten magellanicus* | – | – | – | – | 2 | 1 | 1 | 0 | 0 | 0 | 1 | 1 | – | – | – | – |
| Substrate | 15 | 6 | 7 | 7 | 18 | 5 | 8 | 0 | 6 | 2 | 2 | 1 | 7 | 2 | 3 | 2 |

*Modiolus modiolus,* and *Aequipecten irradians* were tested with *O. seminuda* and *O. bisuturalis*. The results demonstrate that *O. seminuda* preferred *C. fornicata* but this ectoparasite was occasionally found with the other available hosts and showed some preferential behaviour toward *A. irradians*. It was apparent that *O. bisuturalis* found *A. irradians* and its original host, *C. virginica,* about equally attractive.

In the final experiment (Table 4), a larger variety of hosts was offered to the two ectoparasites. Some hosts were withdrawn and others substituted during the trials. The parasite, *O. seminuda,* preferred *C. fornicata, A. irradians,* and *C. striatum.* When *C. fornicata* was not available (see trials 3–5), *A. irradians* was the preferred host with *C. striatum* and *M. modiolus* second, but when *C. fornicata* was reintroduced (trials 6–8) the attraction of *O. seminuda* for *C. fornicata* again became apparent. *Odostomia bisuturalis,* on the other hand, showed a marked preference for *A. irradians,* and at times almost ignored its original host, *C. virginica.* In this experiment, the two ectoparasites spent approximately 40 per cent of the time on the substrate.

All of the experiments show that neither species of *Odostomia* is completely host-specific. Rather, a continuum of preferences was exhibited by both *O. bisuturalis* and *O. seminuda.* The preferences of *O. seminuda* appeared in the order : 1, *C. fornicata;* 2, *A. irradians*; 3, *C. striatum*; 4, *M. modiolus.* Occasionally it is found on all other hosts offered, except *Arctica islandica.* The sequence for *O. bisuturalis* appears to give priority to *A. irradians,* with *C. virginica* and *C. striatum* variously second or third. Other hosts were attacked only rarely. Both ectoparasites were commonly found on the substrate and *O. bisuturalis* spent relatively more of its time on the substrate than did *O. seminuda.*

## SUMMARY

Experiments demonstrate that a range of hosts exists for the ectoparasites *Odostomia seminuda* and *O. bisuturalis*. Definite trends towards host-specificity are present and detectable, but some measure of non-specificity is retained. The maintenance of some element of non-specificity may be an adaptive characteristic which insures the survival of the species in areas in which preferred hosts are absent. In addition, it is shown that the ectoparasites spend much of their time on the substrate between feeding periods.

## ACKNOWLEDGMENTS

Dr Robert Robertson of the Academy of Natural Sciences of Philadelphia confirmed the identity of the species of *Odostomia*. Dr Joseph Rosewater of the Division of Mollusks, United States National Museum, Dr J. Frances Allen of the National Science Foundation, Washington, D.C., and Mr John F. Peake of the British Museum (Natural History) read and criticized the manuscript. Mr Kjell Sandved aided in the photography of the specimens.

## REFERENCES

Adams, C. B., 1839. Observations of some species of the marine shells of Massachusetts, with descriptions of five new species. *Boston J. nat. Hist.* **2**, 262–288.

Allen, J. F., 1954. Notes on the gastropods collected in the vicinity of Chrisfield, Maryland. *Nautilus* **67**, 92–94.

Allen, J. F., 1958. Feeding habits of two species of *Odostomia. Nautilus* **72**, 11–15.

Ankel, F. and Christensen, A. M., 1963. Non-specifity [sic] in host selection by *Odostomia scalaris* Macgillivray. *Vidensk. Medd. dansk. naturh. Foren. Kbh.* **125**, 321–325.

Cole, H. A. and Hancock, D. A., 1955. *Odostomia* as a pest of oysters and mussels. *J. mar. biol. Ass. U.K.* **34**, 25–79.

Fretter, V. and Graham, A., 1949. The structure and mode of life of the Pyramidellidae, parasitic opisthobranchs. *J. mar. biol. Ass. U.K.* **28**, 493–532.

Gardiner, A. P., 1934. The littoral zone. *J. Conch.* **20**, 65–76.

Hackney, A. G., 1944. List of mollusca from around Beaufort, North Carolina, with notes on *Tethys. Nautilus* **58**, 56–64.

Laseron, C. P., 1951. The New South Wales Pyramidellidae and the genus *Mathilda. Rec. Aust. Mus.* **22**, 298–334.

Loosanoff, V. L., 1956. Two obscure oyster enemies in New England waters. *Science* **123**, 1119–1120.

Merrill, A. S. and Boss, K. J., 1964. Reactions of hosts to proboscis penetration by *Odostomia seminuda* (Pyramidellidae). *Nautilus* **78**, 42–45.

Pelseneer, P., 1928. Les parasites des mollusques et les mollusques parasites. *Bull. Soc. zool. Fr.* **53**, 158–189.

Robertson, R., 1957. Gastropod host of an *Odostomia. Nautilus* **70**, 96–97.

Robertson, R. and Orr, V., 1961. Review of pyramidellid hosts, with notes on an *Odostomia* parasitic on a chiton. *Nautilus* **74**, 85–91.

Sanders, H. L., 1958. Benthic studies in Buzzards Bay. 1. Animal-sediment relationships. *Limnol. Oceanogr.* **3**, 245–258.

Smith, E. A., 1899. Descriptions of new species of South African marine shells. *J. Conch.* **9,** 247–252.

Wells, H. W. and Wells, M. J., 1961. Three species of *Odostomia* from North Carolina, with description of new species. *Nautilus* **74,** 149–157.

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## BENTHIC ECOLOGY AND FAUNAL CHANGE IN THE ESTUARY OF THE PATUXENT RIVER.

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**(Abstract)**

**A series of benthic samples was taken at dredging stations at 10, 65, and 130 feet in June and December 1964, off Point Patience in the lower Patuxent River, near Solomons, Maryland. Samples of the fauna from each collection at each station were compared to assess the ecological effects of summer and winter conditions and of water depth.**

**The American oyster, *Crassostrea virginica* (Gmelin), was taken at all stations. Particular attention was paid to its occurrence at the unusual depth of 130 feet. The ecology of the deep-water population of oysters was compared with that of oyster populations of shallower stations. Growth indices were calculated for the oysters and for the other dominant bivalve, the ribbed mussel, *Brachidontes recurvus* (Rafinesque). The size frequency of the oysters was clearly divisible into two means (first-year and larger oysters), each of which showed growth at all three stations at the end of the 7-month period. The oysters taken from 65 and 130 feet showed less growth than the shallow-water population, and many had failed to spawn completely by December. The size frequency of the ribbed mussel could not suitably be divided into different means. The higher modes of the winter samples suggest that a slow development of the young mussels was continuous. The summer populations of both the oyster and the mussel were strongly diminished by December.**

**The deep-water winter stations were characterized by a dramatic increase in the numbers of the ascidean, *Mogula manhattensis* (DeKay), and the mud-snail, *Nassarius vibex* (Say). The red-finger sponge, *Microciona prolifera* (Ellis and Solander), appeared in dominant numbers at mid-depth. The population of the sea anemone, *Aiptasia eruptaurantia* (Field) declined at the 130-foot depth as did its predator species, the wentle trap, *Epitonium rupicola* (Kurtz).**

**The changes in faunal composition suggest that epizoic organisms, such as *Mogula* and *Microciona*, adversely affect growth of the sedentary oysters and mussels whose shells provide a substrate.**

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# THE DISTRIBUTION OF NUTRIENTS IN THE COSTA RICA DOME IN THE EASTERN TROPICAL PACIFIC OCEAN

BY WILLIAM W. BROENKOW

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by William W. Broenkow

# THE DISTRIBUTION OF NUTRIENTS IN THE COSTA RICA DOME IN THE EASTERN TROPICAL PACIFIC OCEAN

*William W. Broenkow*
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## ABSTRACT

The distributions of salinity, dissolved oxygen, phosphate, nitrate, and silicate in the Costa Rica Dome are described from data collected during the Costa Rica Dome cruise November–December 1959. The dome is an area where nutrient-rich, oxygen-poor water is brought to the surface by upwelling.

The ratios of change of oxygen, phosphate, and nitrate are computed statistically from the observed data to 1,100 m depth.

A simple mixing model is used to explain the observed vertical distribution of oxygen above 65 m when allowances are made for photosynthetic oxygen production. The contributions of oxygen from various sources are estimated by use of the model. A similar model is used to compute the ratios in which nutrients are assimilated by phytoplankton.

## INTRODUCTION

The Costa Rica Dome (Cromwell 1958) is an area approximately 400 km in diameter centered near 8° N lat, 89° W long, in the eastern tropical Pacific Ocean where the isothermal surface layer is extremely shallow. Wyrtki (1964) has described the physical oceanography of this area on the basis of observations made during the Costa Rica Dome cruise, November–December 1959 (Scripps Institution of Oceanography 1960) (Fig. 1), and he has suggested a mechanism that maintains upwelling in the dome. His results are summarized below.

The anticlinal thermal structure, or dome, is located at the eastern extremity of the thermal ridge that separates the North Equatorial Countercurrent from the North Equatorial Current. Wyrtki states that the dome may be caused by the northward deflection of the countercurrent as it impinges on the coast of Central America, causing a redistribution of mass that is effected by divergence and crosscurrent flow. He has computed an average ascending velocity within the dome of $10^{-6}$ m/sec and has estimated that the upwelling originates between depths of 75 and 200 m. The northward transport across the eastern limb of the dome was about $20 \times 10^6$ $m^3$/sec, whereas the vertical transport or upwelling was only $7 \times 10^4$ $m^3$/sec. The dome has been observed several times and appears to be a permanent feature, although it may vary seasonally in magnitude and position.

The upwelling had a pronounced effect on the distribution of properties at the sea surface (Figs. 2b, c, d). Surface manifestations of the ascending motion were the higher salinities, lower oxygen contents, and higher nutrient concentrations in the surface water in the dome than in the surrounding surface waters.

The author wishes to thank Mr. E. B. Bennett of the Inter-American Tropical Tuna Commission for the many helpful criticisms and suggestions that he offered during this work. Dr. K. Wyrtki is gratefully acknowledged for offering some of his illustrations for use in this paper. The Costa Rica Dome survey was conducted jointly by the Inter-American Tropical Tuna Commission and Scripps Institution of Oceanography.

## METHODS

During the Costa Rica Dome cruise, 6 November through 14 December 1959, 50 hydrographic stations were occupied in the area of the dome (Fig. 1). At all stations, salinity, temperature, dissolved oxygen, and inorganic phosphate were observed to at least 1,000 m. At 16 of these stations, inorganic nitrate, nitrite, and reactive silicate were observed. In addition, 8 shallow stations were occupied, and 48 surface samples were taken in the vicinity of Cocos

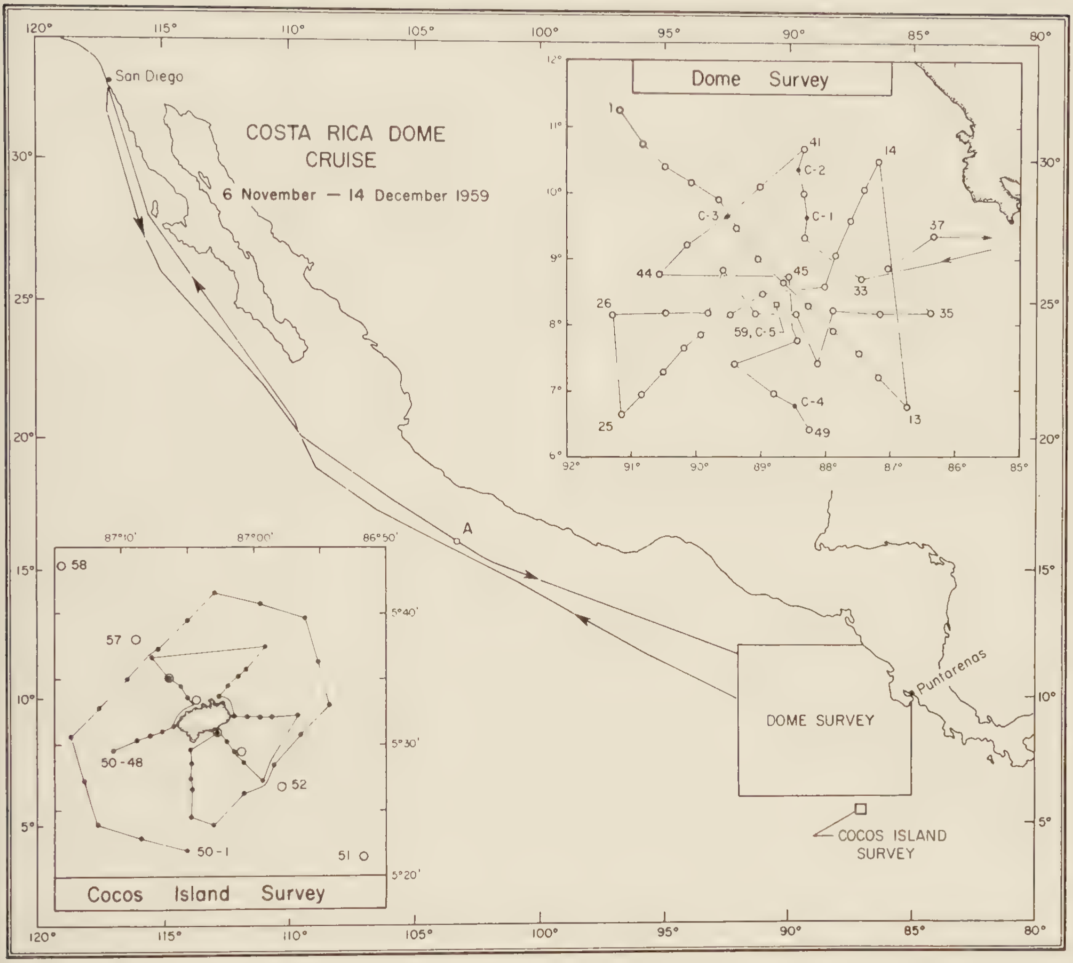
COSTA RICA DOME CRUISE
6 November — 14 December 1959
San Diego
Dome Survey
DOME SURVEY
Puntarenas
COCOS ISLAND SURVEY
Cocos Island Survey
A
120°
115°
110°
105°
100°
95°
90°
85°
80°
30°
25°
20°
15°
10°
5°
C-1
C-2
C-3
C-4
59, C-5
13
14
25
26
33
35
37
41
44
45
49
50-48
50-1
51
52
57
58

Fig. 1. Track chart of Costa Rica Dome cruise, 9 November to 14 December 1959.

Island, about 275 km south of the dome's center.

Dissolved oxygen analyses were done by the Winkler method, and oxygen solubilities were based on the solubility data of Truesdale, Downing, and Lowden (1955). Inorganic phosphate concentrations were determined by the method described by Strickland and Parsons (1960), and temperature corrections were applied as described by Wooster and Rakestraw (1951). Samples for nitrate, nitrite, and silicate were frozen aboard ship and later analyzed ashore using methods described by Strickland and Parsons (1960). Productivity measurements were made using the $C^{14}$ technique of Steemann Nielsen (1952).

## VERTICAL DISTRIBUTIONS

A characteristic of the eastern tropical Pacific is the shallow, mixed surface layer. It is only 20–30 m deep near the American coast and increases in depth to 50–70 m at 130° W long (Wyrtki, in press). This shallow thermocline is probably a consequence of a general ascending motion throughout the eastern tropical Pacific north of the equator that is caused by surface waters being driven westward by persistent northeast trade winds. Extremely high nutrient and low oxygen concentrations are found in the intermediate water in this area, demonstrating that this water has undergone chemical change due either to a long residence or to an abundance of oxidizable ma-

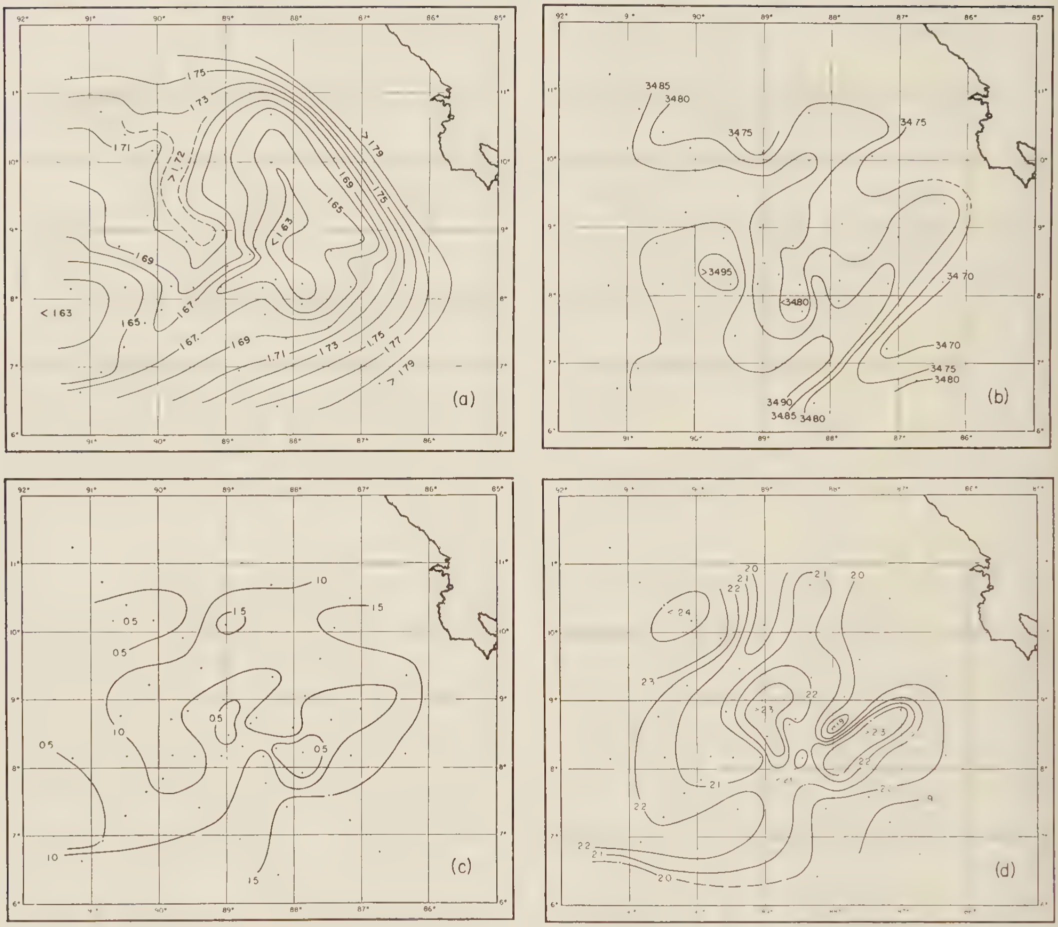

Fig. 4. Distribution of properties at 50 m during Costa Rica Dome cruise, November–December 1959: (a) Geopotential topography of the 50-decibar surface relative to 1,000 decibars, dynamic m; (b) 50-m salinity, ‰; (c) 50-m oxygen, ml/liter; (d) 50-m phosphate, $\mu$g-at./liter.

coast and in the low-salinity water along the 89th meridian. Near Cocos Island, phosphate concentrations were about 0.4 $\mu$g-at./liter.

The oxygen distribution at the surface (Fig. 2c) was patchy and not clearly related to the circulation. At all stations in the dome, the surface water was undersaturated with oxygen. Surface concentrations ranged from 3.51 to 4.56 ml/liter (between 76.7 and 99.9% saturation). Lowest concentrations were observed near the phosphate and salinity maxima at 8° N lat, 88° W long. Near Cocos Island, surface oxygen contents were about 101% of the equilibrium solubility. At 50 m, the relation between circulation, salinity, oxygen, and phosphate may be clearly seen (Figs. 4a, b, c, d). At this depth, the salinity varied between 34.70 and 34.95‰ and was apparently little affected by coastal precipitation. Lowest oxygen concentrations ($< 0.5$ ml/liter) were coincident with highest phosphate concentrations ($> 2.2$ $\mu$g-at./liter). All the distributions show the influence of cyclonic circulation and upwelling.

The nitrate and silicate distributions were consistent with the phosphate and salinity distributions both at the surface and at 50 m. High nitrate and silicate concentrations were observed where salinity and phosphate contents were high. The horizontal distributions of nitrate and silicate are not presented here, because these properties were observed at only one-third of the stations.

## NUTRIENT RELATIONSHIPS

As organic matter is metabolized in the sea, organically bound phosphorus and nitrogen are returned to solution by bacterial oxidation. Simultaneously, dissolved oxygen is consumed (that is, the apparent oxygen utilization, or AOU, is increased). Upon complete oxidation of the organic matter, the phosphorus, nitrogen, and carbon that have been chemically combined in the organism are released into solution as inorganic phosphate, nitrate, and carbonate ions. The proportions in which they are released are determined by the proportions in which they were present in the living organism. Conversely, as phytoplankton synthesizes nutrients in the euphotic zone, inorganic phosphorus, nitrogen, and carbon become organically combined, and oxygen is produced as a by-product.

There is a growing body of evidence to suggest that oxygen, carbon, nitrogen, and phosphorus are assimilated and subsequently regenerated in the atomic ratios −276 : 106 : 16 : 1 (*see* Redfield, Ketchum, and Richards 1963). There are certain notable exceptions to this statistical relationship that will not be dealt with here.

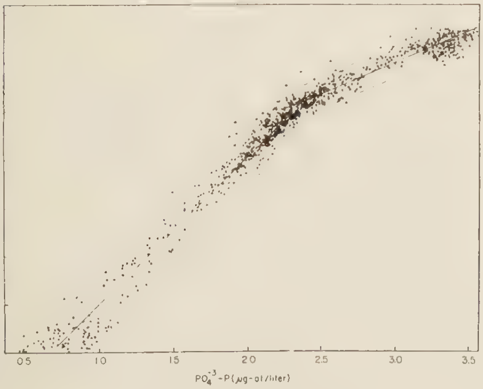

FIG. 5. Apparent oxygen utilization (AOU), ml/liter, vs. phosphate, µg-at./liter, in the Costa Rica Dome. The computed slopes are $\Delta AOU : \Delta P = 274 : 1$ by atoms for AOU $\leqq$ 5.0 ml/liter and $\Delta AOU : \Delta P = 114 : 1$ by atoms for AOU $>$ 5.0 ml/liter. The dashed lines indicate the 95% confidence limits.

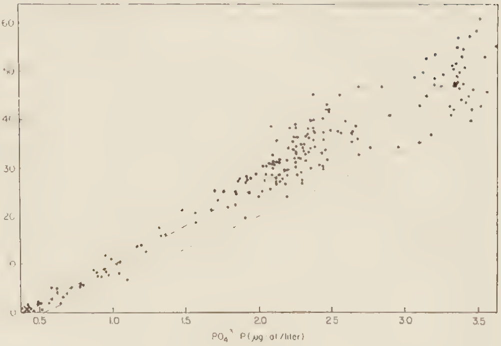

FIG. 6. Nitrate vs. phosphate, µg-at./liter, in the Costa Rica Dome. The computed slope is $\Delta N : \Delta P = 16.5 : 1$ by atoms. The dashed lines indicate the 95% confidence limits. The symbol × represents the average surface value near Cocos Island that was not used in the regression analysis.

In the Costa Rica Dome, the relationship between AOU and inorganic phosphate is not linear (Fig. 5). An abrupt change in slope is found near the value AOU $= 5.0$ ml/liter, $PO_4^{-3}$-P $= 2.3$ µg-at./liter. Two regression lines were computed for these data: the first for those values of AOU $\leqq 5.0$ ml/liter, representing conditions in the water column above the potential density surface, where sigma-$t = 26.3$ g/liter (above approximately 120 m), the second for values AOU $> 5.0$ ml/liter, representing conditions below sigma-$t = 26.3$ g/liter (between about 120 and 1,100 m). The AOU-phosphate data do not appear to be linear for AOU $> 5.0$ ml/liter, but, for the purpose of demonstrating the differences above and below this value, a linear regression analysis was used for both groups of data.

The nitrate and phosphate data were separated into two groups whose corresponding AOU values were greater than and less than 5.0 ml/liter. The $\Delta N : \Delta P$ regression coefficients for these two groups were not significantly different, and it is concluded that the nitrate : phosphate ratio of change is constant throughout the water column (Fig. 6).

The AOU : phosphate ratio of change in the water above 120 m (that is, AOU $\leqq$

TABLE 1. *Results of linear regression analyses*

Apparent oxygen utilization vs. inorganic phosphate

| Range | *b* (ml/$\mu$g-at.) | $S_{y\|x}$ (ml/liter) | $S_b$ (ml/$\mu$g-at.) | *r* | *n* | $\Delta$AOU : $\Delta$P (atom : atom) |
|---|---|---|---|---|---|---|
| AOU $\lesseqgtr$ 5.0 ml/liter ($\sigma_t \lesseqgtr$ 26.3 g/liter) | 3.07 | ±0.31 | ±0.03 | +0.98 | 420 | 274 : 1 |
| AOU > 5.0 ml/liter ($\sigma_t$ > 26.3 g/liter) | 1.28 | ±0.16 | ±0.02 | +0.96 | 450 | 114 : 1 |

Inorganic nitrate vs. inorganic phosphate

| Range | *b* (atom : atom) | $S_{y\|x}$ ($\mu$g-at./liter) | $S_b$ (atom : atom) | *r* | *n* | $\Delta$N : $\Delta$P (atom : atom) |
|---|---|---|---|---|---|---|
| All data | 16.5 | ±2 ($x = 1.0$)<br>±5 ($x = 3.5$) | ±0.45 | +0.95 | 200 | 16.5 : 1 |

5.0 ml/liter) (Table 1) is in excellent agreement with the normal oxidative ratio $\Delta$AOU : $\Delta$P = 276 : 1 proposed by other authors (Redfield et al. 1963). Because oxygen may be transferred across the sea surface, the $\Delta$AOU : $\Delta$P relation computed from data obtained from the surface layer might not necessarily represent the true oxidative ratio. However, as will be shown in the next section, the addition of oxygen from the surface is probably important only to depths of 20 m. Because the data obtained from the surface to 20 m do not appear to deviate from the regression line established by data collected between 20 and 120 m (Fig. 5), it is probable that the regression line does represent the AOU : phosphate oxidative ratio which has the value 274 : 1 ± 5 at the 95% confidence level.

The $\Delta$AOU : $\Delta$P ratio computed for data collected below 120 m (Table 1) (that is, AOU > 5.0 ml/liter) is less than half the normal oxidative ratio. This low ratio can be explained in terms of the preformed phosphate distribution. In the Costa Rica Dome, the preformed phosphate content (that amount of phosphate that has not been derived from the decomposition of organic material but was present in the dissolved inorganic form when the water sank below the surface) is constant (about 0.65 $\mu$g-at./liter) from the sea surface to the potential density surface sigma-*t* = 26.3 g/liter, the density level at which the change in slope occurs. The depth at which the slope changes varies from place to place but is approximately 120 m. Between this level and the maximum sampling depth, where sigma-*t* = 27.4 g/liter, the preformed phosphate content increases from 0.65 to 1.25 $\mu$g-at./liter. It is likely, although not conclusive, that the AOU : phosphate ratio observed below the level sigma-*t* = 26.3 g/liter results from a mixture of Equatorial Subsurface Water containing little preformed phosphate and intermediate water containing large amounts of preformed phosphate, rather than from a change in the oxidative ratio. The mixture of these two waters containing different amounts of preformed phosphate need not produce a linear AOU : phosphate relationship. This hypothesis is consistent with Redfield's (1942) explanation of the phosphate distribution in the Atlantic Ocean, in which he demonstrated that large amounts of preformed phosphate spread out isentropically from the Antarctic Convergence toward the equator between the levels sigma-*t* = 27.2 and 27.6 g/liter.

The nitrate : phosphate ratio of change is 16.5 : 1 ± 0.9 at the 95% confidence level, in agreement with the previously established value of 16 : 1. The fact that the slope $\Delta$N : $\Delta$P is constant over the complete range of observed values is evidence that the change in slope in the AOU : phosphate relationship is caused by inequalities in the preformed phosphate distribution. The absence of a break in slope in the nitrate : phosphate relationship suggests that the amounts of preformed nitrate and preformed phosphate are equivalent throughout the water column and that the oxidative ratios do not vary.

### THE OXYGEN MODEL

The distribution of oxygen in the sea is determined by a complicated interplay of physical and biological processes. Richards (1957) has reviewed these processes. They are: 1) photosynthetic production in the euphotic zone, 2) atmospheric exchange (gain or loss) at the sea surface, 3) respiratory consumption at all depths, and 4) circulatory and mixing processes. An attempt will be made to estimate the magnitude of these processes in the near-surface layer of the Costa Rica Dome through the use of a simple model.

In this model, the dome is considered to be an area where water of uniform high salinity, high phosphate, and low oxygen concentrations is brought close to the surface by upwelling from some depth *d*. Surface water in the area close to, but uninfluenced by, the dome is assumed to have uniform low salinity, low phosphate, and high oxygen contents. Mixing of these two water types is assumed, so that the fraction of each water type in the mixture is a linear function of salinity. Thus,

$$P_{\text{mixing}} = P_d \frac{(S - S_0)}{(S_d - S_0)} + P_0 \frac{(S_d - S)}{(S_d - S_0)}, \quad (1)$$

where $P_{\text{mixing}}$ is the phosphate content due to mixing in the absence of biological processes, $P_d$ the phosphate content characteristic of the water type at depth *d*, $P_0$ the phosphate content of the surface water type, $S_d$ the salinity of the deep water, $S_0$ the salinity of the surface water, and $S$ the observed salinity at each sampling depth.

Similarly, the oxygen content due to mixing can be computed as

$$O_{\text{mixing}} = O_d \frac{(S - S_0)}{(S_d - S_0)} + O_0 \frac{(S_d - S)}{(S_d - S_0)}, \quad (2)$$

where $O_{\text{mixing}}$ is the oxygen concentration that would result from the mixture of these two water types in the absence of atmospheric exchange and biological processes, $O_d$ the oxygen content of the deep water type, and $O_0$ the oxygen content of the surface water type.

The effect of biological production (or consumption) of oxygen can be estimated from the difference between the observed phosphate concentration and the phosphate concentration computed for the mixture. Thus, the net amount of oxygen produced biologically at each sampling depth would be

$$O_{\text{biol}} = (P - P_{\text{mixing}})\Delta O : \Delta P, \quad (3)$$

where $O_{\text{biol}}$ is the amount of oxygen produced (or consumed, if the value is negative), $P$ the observed phosphate concentration, and $\Delta O : \Delta P$ the ratio of change relating the production of oxygen to the consumption of phosphate.

If the Costa Rica Dome can be considered to be a two-component system, and if the biological production is estimated by equation (3), the oxygen concentration at any depth above *d* is

$$O_{\text{model}} = O_{\text{mixing}} + O_{\text{biol}}, \quad (4)$$

so that $O_{\text{model}}$ is a function of salinity and phosphate.

The boundary conditions, which are the salinity, phosphate content, and oxygen content of the unmixed deep and surface components, must be chosen to represent average values of these water types.

The salinity maximum, as determined by averaging the station data by depth, is found at 105 m. This is the greatest depth at which the model would be valid, because it is assumed that the salinity above the lower boundary is always less than the salinity at this boundary. Because productivity measurements indicate negligible net production below 50 m, the lower boundary is set at 65 m, which is the next lower sampling depth. Limiting the model to 65 m rather than to 105 m reduces the possible effects of lateral mixing processes that are unaccounted for by the model. The boundary conditions determined by averaging the station data at 65 m and their respective standard deviations from the mean are: $S_d = 34.85‰ \pm 0.05‰$, $P_d = 2.13$ µg-at./

TABLE 2. *Average observed and computed distributions of oxygen in the Costa Rica Dome**

| Depth (m) | Observed oxygen (ml/liter) | Computed oxygen (ml/liter) | Produced biologically in ml/liter (%) | Mixed from surface in ml/liter (%) | Upwelled from depth in ml/liter (%) | Model anomaly in ml/liter (%) |
|---|---|---|---|---|---|---|
| 0 | 4.19 | 3.91 | 0.60<br>(15) | 3.01<br>(77) | 0.30<br>(8) | +0.28<br>(7) |
| 10 | 3.72 | 3.59 | 0.86<br>(24) | 2.24<br>(62) | 0.49<br>(14) | +0.13<br>(4) |
| 20 | 2.22 | 2.37 | 0.87<br>(37) | 0.70<br>(29) | 0.80<br>(34) | –0.15<br>(6) |
| 30 | 1.56 | 1.60 | 0.49<br>(31) | 0.19<br>(12) | 0.92<br>(57) | –0.04<br>(2) |
| 40 | 1.19 | 1.22 | 0.22<br>(18) | 0.05<br>(4) | 0.95<br>(78) | –0.03<br>(2) |
| 50 | 1.04 | 1.01 | 0.03<br>(3) | 0.02<br>(2) | 0.96<br>(95) | +0.03<br>(3) |
| 65 | 0.96 | 0.99 | 0.03<br>(3) | 0.00<br>(0) | 0.96<br>(97) | –0.03<br>(3) |

* This table gives the average results of computations using the oxygen model described in the text. Each value represents data from 50 stations. The computed oxygen concentrations are the sums of contributions from biological production (equation [3]) and from oxygen originally present in the two water components (equation [2]); the model anomaly is the difference between the observed and computed oxygen contents. The numbers in parentheses are the percentages of the computed total oxygen content at the corresponding depths.

liter ± 0.14 μg-at./liter, $O_d = 0.96$ ml/liter ± 0.32 ml/liter.

The salinity, phosphate, and oxygen contents of the surface water component were taken from the values observed around Cocos Island (Fig. 1). These averages and their standard deviations computed from 48 observations near the island are: $S_0 = 33.00‰ \pm 0.05‰$, $P_0 = 0.41$ μg-at./liter ± 0.04 μg-at./liter, and $O_0 = 4.57$ ml/liter ± 0.18 ml/liter (101% of saturation). Bennett's (1963) surface salinity chart shows that surface conditions near Cocos Island are representative of the area south of the Costa Rica Dome and that the surface properties near the island are probably not greatly influenced by the dome. Cocos Island lies in the path of the North Equatorial Countercurrent, and surface water near the island is probably representative of water that is mixed into the upwelling region. The low-salinity water near the coast is assumed to be confined to coastal areas and not to play an important role in the mixing process.

The oxidative ratio $\Delta O : \Delta P$ is taken as –276 : 1 by atoms or –3.09 : 1 ml $O_2$ : μg-at. $PO_4^{-3}$-P, which is the normal value proposed by Redfield et al. (1963). The use of this value is justified on the basis of the $\Delta AOU : \Delta P$ ratio computed statistically from observed data.

### RESULTS OF THE OXYGEN MODEL

The oxygen model was used to compute the vertical distribution of oxygen at the 50 stations occupied during the Costa Rica Dome cruise. The average results of these calculations (Table 2) are separated into three components: a) oxygen produced biologically, b) oxygen mixed into the dome with surface water, and c) oxygen originally present in the deep water that upwelled from depth. Component a) was computed from equation (3), while b) and c) were computed from the two terms in equation (2).

The vertical distribution of oxygen produced by photosynthesis and that of the incubator productivity are similar in shape (Fig. 7), and although the maximum in the distribution of oxygen due to biological production coincides with the maximum in productivity, these maxima result from different processes. This is readily seen from the following argument.

If there were no mixing, and if upwelling brought undiluted deep water directly to the surface, the oxygen content due to biological production would increase from zero at the compensation depth to a maximum at the surface. That is, as water ascends through the euphotic zone, oxygen accumulates owing to photosynthetic production. The distribution of oxygen resulting from this process alone would, in effect, be proportional to the integral of the productivity distribution from the compensation depth to the depth in question. The effect of mixing surface water with deep water, as assumed in the model, can be compensated for by dividing the oxygen content due to biological production by the fraction of deep water at each depth. The amount of oxygen produced biologically in a unit volume of upwelled deep water is estimated in this way. The distribution of oxygen produced biologically in a unit volume of deep water (Fig. 7) shows that this quantity is nearly zero at 65 m, increases to a maximum value at the surface, and exhibits its maximum gradient at the depth of the productivity maximum. Therefore, the distribution of oxygen produced per unit volume of deep water is consistent with the productivity distribution, and the similar shapes of the biological oxygen curve as estimated from the model and the distribution of productivity are a consequence of the mixing processes. The subsurface productivity maximum is generally attributed to light inhibition at the surface.

If the model accurately describes the net biological production of oxygen, these values should agree with productivity measurements. Integrating the oxygen content resulting from biological production from 65 m to the surface gives $2.9 \times 10^4$ ml $O_2/m^2$. If the ratio of oxygen production to carbon assimilation by atoms is $\Delta O : \Delta C = -276 : 106$, the net amount of carbon fixed would be $1.2 \times 10^4$ mg $C/m^2$. Under the assumptions of the model, it is estimated that 87% of the water above 65 m has been upwelled at a velocity of $10^{-6}$ m/sec (Wyrtki 1964). Therefore, the net productivity estimated from the model is 190 mg C $m^{-2}$ $day^{-1}$, which agrees well with *in situ* productivity measurements of between 160 and 440 mg C $m^{-2}$ $day^{-1}$.

The distributions of oxygen derived from the surface and deep water components (Table 2) are inversely related. At the surface, 77% of the oxygen content originated in what is assumed to be surface water like that observed near Cocos Island, and only 8% was upwelled from depth. At 50 m, there is a 2% contribution from the surface and a 95% contribution from deep water. Between 10 and 50 m, the distribution of oxygen that has been mixed into the water column with surface water is exponential (Fig. 8). Broenkow and Bennett (unpublished data) have shown that an exponential distribution could be expected in a two-component system with upwelling, and the observed distribution supports the assumed mixing process. It should be repeated for the sake of clarity that the computed distributions of oxygen mixed from the surface and deep water components are merely functions of salinity (*see* equation [2]).

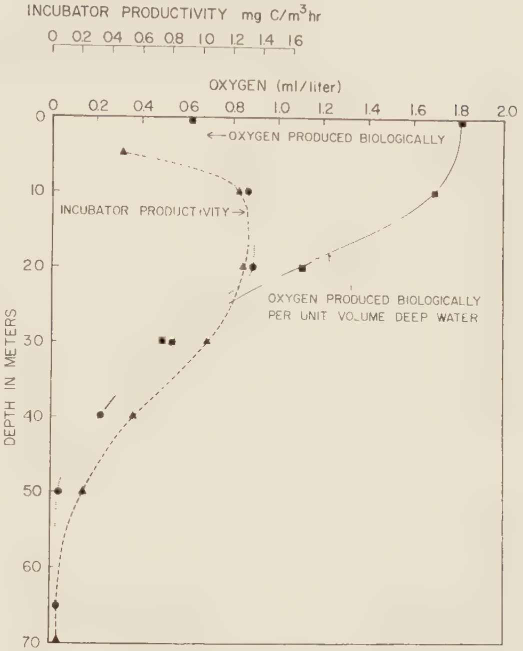

FIG. 7. Average vertical distributions of oxygen produced biologically computed from the model and oxygen produced biologically per unit volume of deep water, ml/liter; average vertical distribution of incubator productivity from 11 stations in the Costa Rica Dome, mg C $m^{-3}$ $hr^{-1}$. The amount of oxygen produced biologically per unit volume of deep water is the amount of oxygen produced biologically at each depth divided by the fraction of deep water at that depth.

The distribution of the model anomaly, which is the difference between the observed and computed oxygen concentrations, shows the effect of oxygen exchange with the atmosphere (Table 2). Because the model does not allow for exchange of oxygen across the sea surface, these effects can be deduced only from the model anomaly. At the surface and at 10 m, the observed oxygen content is greater than that computed from the model by 7 and 4% of the computed contents at those depths. Because the surface layer in the Costa Rica Dome is everywhere undersaturated with

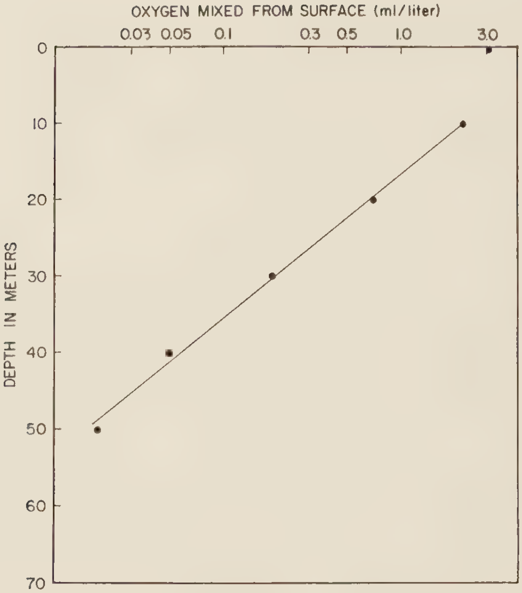

FIG. 8. Average vertical distribution of oxygen, computed from the model, that has been mixed into the water column with surface water, ml/liter, logarithmic plot.

oxygen (Fig. 2c), it is likely that these anomalies result from a net transport of oxygen into the sea. The anomalies between the surface and 20 m are significant at the 95% confidence level. Below 20 m, the differences between the model and observations are not significant at the 95% level. The standard error of estimate of the model anomaly is constant with depth and is ± 0.3 ml $O_2$/liter.

## THE NUTRIENT MODEL

A model similar to the oxygen model can be applied to the nitrate and silicate distributions. The assumptions involved in the oxygen model also apply to the nutrient model. Because the nitrate and silicate contents in the surface water near Cocos Island are negligible, nutrient models analogous to equation (4) become

$$N_{\text{model}} = N_d \frac{(S - S_0)}{(S_d - S_0)} + (P - P_{\text{mixing}}) \Delta N : \Delta P \qquad (5)$$

and

$$Si_{\text{model}} = Si_d \frac{(S - S_0)}{(S_d - S_0)} + (P - P_{\text{mixing}}) \Delta Si : \Delta P , \qquad (6)$$

where $N_{\text{model}}$ and $Si_{\text{model}}$ are the nitrate and silicate contents computed from the model. $N_d$ and $Si_d$ are the nitrate and silicate concentrations at $d = 65$ m and equal 29.3 $\mu$g-at. $NO_3^-$-N/liter and 21.0 $\mu$g-at. $SiO_4^{-4}$-Si/liter. $\Delta N : \Delta P$ and $\Delta Si : \Delta P$ are the assimilation ratios of change that relate nitrate and silicate consumption to the phosphate consumption.

The ratio of change $\Delta N : \Delta P$ is well known and has been estimated by numerous authors to be between 15 : 1 and 16 : 1 (Redfield et al. 1963). The value $\Delta N : \Delta P =$ 16 : 1 was used in these computations and is within the range computed statistically (Table 1). There is, however, no universal regeneration or assimilation ratio that can be used in the silicate model. The analysis of plankton gives Si : P concentration ratios varying between 16 : 1 and 50 : 1 (Vinogradov 1953). Richards (1958) found the ratio of change $\Delta Si : \Delta P = 15 : 1$ for waters of the western Atlantic, and Stefánsson and Richards (1963) found the ratio of change $\Delta Si : \Delta P = 22 : 1$ in the eastern North Pacific.

Assuming that the model can be used to describe the silicate distribution, the silicate content calculated from the model should equal the observed silicate concentration, and equation (6) can then be rewritten

$$\Delta Si : \Delta P = \frac{Si_d \dfrac{(S - S_0)}{(S_d - S_0)} - Si}{P_d \dfrac{(S - S_0)}{(S_d - S_0)} + P_0 \dfrac{(S_d - S)}{(S_d - S_0)} - P} , \qquad (7)$$

where $Si$ refers to the observed silicate concentrations. The numerator of equation (7) is termed the "silicate anomaly" after Stefánsson and Richards (1963), and the denominator is termed the "phosphate anomaly." The regression coefficient of the numerator on the denominator is the silicate : phosphate ratio of change.

The nitrate concentrations computed from the model agree with observations (Fig. 9). The regression coefficient of the computed vs. the observed data is + 0.97, which is not significantly different from

1.0. This suggests that the assumed assimilation ratio, $\Delta N : \Delta P = 16 : 1$, applies and also that the nutrient model could be used to estimate the $\Delta Si : \Delta P$ ratio of change.

The regression line (Fig. 10) computed to determine the ratio of change $\Delta Si : \Delta P$ (based on 91 samples) is

$$\text{silicate anomaly} = 0.7 + 16.2 \times \text{phosphate anomaly},$$

where the silicate anomaly is the numerator and the phosphate anomaly the denominator in equation (7). The ratio of change expressed by atoms is

$$\Delta Si : \Delta P = 16.2 : 1 \pm 1.6 \text{ (at the 95\% confidence level)}.$$

The fact that the regression line does not pass through the origin is probably due to small inaccuracies in the boundary conditions.

## CONCLUSIONS

The distributions of the nutrients and oxygen in the Costa Rica Dome are determined mainly by the localized upwelling of nutrient-rich, oxygen-poor water from 65 m or deeper and its subsequent mixing with surface water having high oxygen and low nutrient contents. As the water ascends through the euphotic zone, the distributions of these chemical properties are further modified by biological consumption of nutrients.

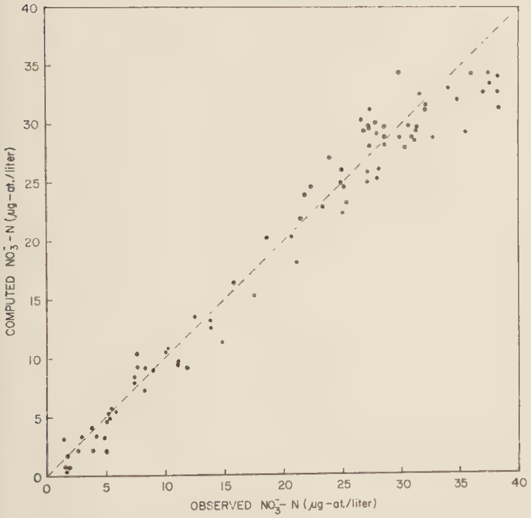

Fig. 9. Nitrate content computed from model vs. observed nitrate, µg-at./liter. Dashed line indicates 1 : 1 correlation.

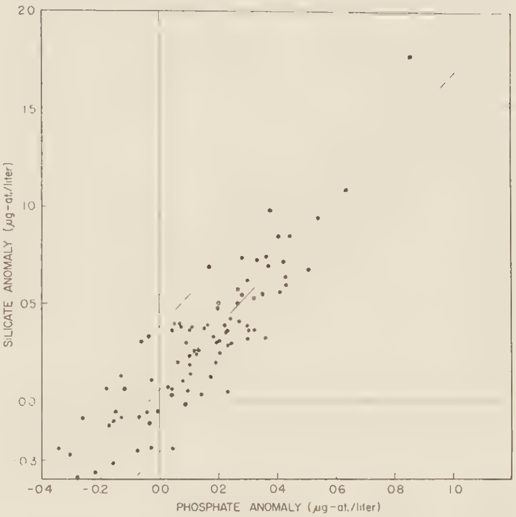

Fig. 10. Silicate anomaly vs. phosphate anomaly, µg-at./liter. The anomalies are the differences between the observed silicate and phosphate concentrations and those computed for a mixture of deep and surface waters (equation [7]). Computed slope is $\Delta Si : \Delta P = 16.2 : 1$. Dashed lines indicate 95% confidence limits.

Assuming that the surface layer of the Costa Rica Dome is a two-component mixture of water upwelled from 65 m and surface water, and that the proportions of water from each of these sources can be estimated from the observed salinity, the distribution of oxygen was estimated on the basis of the phosphate content. The average computed oxygen distribution agrees well with the average observed distribution except at the surface, where the atmospheric exchange of oxygen is important. The gross oxygen budget above 65 m is estimated as: 38% of the oxygen content was present in the deep water before upwelling, 37% was present in the surface water and was mixed into the dome, 22% was biologically produced *in situ*, and 3% entered the sea by atmospheric exchange.

The average rate of carbon fixation based on the model is about 190 mg C $m^{-2}$ $day^{-1}$. As much as 10 µg-at./liter of silicate-silicon, 10 µg-at./liter nitrate-nitrogen, and 0.6 µg-at./liter of phosphate-phosphorus were consumed by photosynthetic activity in the dome as the water was upwelled. Silicate, nitrate, and phosphate appear to be biologically utilized in the atomic ratio 16 : 16 : 1.

The ratio of change $\Delta$AOU : $\Delta$P as computed by regression analysis is not constant in the dome. An abrupt change in the ratio is found at the potential density surface sigma-$t = 26.3$ g/liter. Above this surface (AOU $\overset{=}{<}$ 5.0 ml/liter), the atomic ratio of change is $\Delta$AOU : $\Delta$P = 274 : 1, and below this surface (AOU > 5.0 ml/liter) the ratio is $\Delta$AOU : $\Delta$P = 114 : 1. The change in slope is thought to be due to an increasing amount of preformed phosphate below the surface sigma-$t = 26.3$ g/liter. The $\Delta N : \Delta P$ ratio of change is 16.5 : 1 and is constant over the concentration range observed in the dome.

## REFERENCES

BENNETT, E. B. 1963. An oceanographic atlas of the eastern tropical Pacific Ocean, based on data from Eastropic Expedition, October–December 1955. Inter.-Am. Trop. Tuna Comm. Bull., **8**: 33–165.

CROMWELL, T. 1958. Thermocline topography, horizontal currents and "ridging" in the eastern tropical Pacific. Inter.-Am. Trop. Tuna Comm. Bull., **3**: 135–164.

PETERSON, C. L. 1960. The physical oceanography of the Gulf of Nicoya, Costa Rica, a tropical estuary. Inter.-Am. Trop. Tuna Comm. Bull., **4**: 139–216.

REDFIELD, A. C. 1942. The processes determining the concentration of oxygen, phosphate and other organic derivatives within the depths of the Atlantic Ocean. Papers Phys. Oceanog. Meteorol., **9**(2): 1–22.

———, B. H. KETCHUM, AND F. A. RICHARDS. 1963. The influence of organisms on the composition of sea-water, p. 26–77, v. 2. *In* M. N. Hill, E. D. Goldberg, C. O'D. Iselin, and W. H. Munk [eds.], The sea. Interscience, London.

RICHARDS, F. A. 1957. Oxygen in the ocean, p. 185–238, v. 1. *In* J. W. Hedgpeth [ed.], Treatise on marine ecology and paleontology. Geol. Soc. Amer. Mem., 67.

———. 1958. Dissolved silicate and related properties of some western North Atlantic and Caribbean waters. J. Marine Res., **17**: 449–465.

SCRIPPS INSTITUTION OF OCEANOGRAPHY, UNIVERSITY OF CALIFORNIA. 1960. Physical chemical and biological data Costa Rica Dome cruise. SIO Reference Report 80-20, 32 p. (unpublished manuscript).

STEEMANN NIELSEN, E. 1952. The use of radioactive carbon ($C^{14}$) for measuring organic production in the sea. J. Conseil, Conseil Perm. Intern. Exploration Mer, **18**: 117–140.

STEFÁNSSON, U., AND F. A. RICHARDS. 1963. Processes contributing to the nutrient distributions off the Columbia River and Strait of Juan de Fuca. Limnol. Oceanog., **8**: 394–410.

STRICKLAND, J. D. H., AND T. R. PARSONS. 1960. A manual of sea water analysis. Bull. Fisheries Res. Board Can. No. 125. 185 p.

TRUESDALE, G. A., A. L. DOWNING, AND G. P. LOWDEN. 1955. The solubility of oxygen in pure water and sea-water. J. Appl. Chem., **5**: 53–62.

VINOGRADOV, A. P. 1953. The elementary chemical composition of marine organisms. Mem. Sears Found. Marine Res., **2**: 647 p.

WOOSTER, W. S., AND N. W. RAKESTRAW. 1951. The estimation of dissolved phosphate in sea water. J. Marine Res., **10**: 91–100.

WYRTKI, K. 1964. Upwelling in the Costa Rica Dome. U.S. Fish Wildlife Serv. Fishery Bull., **63**: 355–372.

———. 1964. The thermal structure of the eastern Pacific Ocean. Deut. Hydrograph. Z. Ergänzungsheft. 84 p.

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# Meristic Counts of Striped Bass from Alabama

In 1960 and 1961, 18 striped bass (*Roccus saxatilis*) caught by anglers from the Tallapoosa River near Tallassee, Alabama, and one fish caught from the Alabama River near the city of Montgomery (the Tallapoosa is a tributary of the Alabama River, which flows into the Gulf of Mexico) were examined by the author. The fish ranged from 16 to 39 inches in total length. Counts of several meristic characters were made in the manner described by Hubbs and Lagler (1949). The frequency distributions of the counts of the meristic characters studied are presented in Table 1. The character index (Raney and deSylva, 1953) is the combined total of soft rays from the anal, dorsal, and both pectoral fins. The mean number of lateral-line scales in this sample was 66.3 with a standard error of the mean of 0.29.

Raney and Woolcott (1955) reported counts from a sample of four fish from the Gulf Coast. Murawski (unpublished) added counts from seven more Gulf Coast fish. A mean of 65.9 lateral-line scales was estimated for these 11 fish. Combining the counts from these 11 fish with the 19 from the present study, a mean of 66.2 lateral-line scales was estimated for striped bass collected from the Gulf Coast.

Few studies have been made of Gulf Coast striped bass in contrast to the extensive investigations along the Atlantic Coast. Murawski (unpublished) reviewed previous work done on the Atlantic and Gulf Coasts and compared populations of striped bass on the basis

TABLE 1.—*Frequency distribution of meristic characters of striped bass in Alabama*

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Lateral-line scales | 64 | 65 | 66 | 67 | 68 | $\bar{x}$ | $S_{\bar{x}}$ |
| frequency | 1 | 5 | 5 | 4 | 4 | 66.3 | 0.29 |
| Character index | 54 | 55 | 56 | 57 | 58 | $\bar{x}$ | $S_{\bar{x}}$ |
| frequency | 1 | 2 | 4 | 11 | 1 | 56.5 | 0.22 |
| Pectoral rays | 32 | 33 | 34 | 35 | 36 | $\bar{x}$ | $S_{\bar{x}}$ |
| frequency | 2 | 2 | 14 | | 1 | 33.8 | 0.13 |
| Anal rays | 10 | 11 | | | | $\bar{x}$ | |
| frequency | 3 | 16 | | | | 10.8 | |
| Dorsal rays | 11 | 12 | | | | $\bar{x}$ | |
| frequency | 3 | 16 | | | | 11.8 | |
| Dorsal spines | 8 | 9 | | | | $\bar{x}$ | |
| frequency | 1 | 18 | | | | 8.9 | |

of lateral-line scale counts. The greatest average number of lateral-line scales reported for the various samples from the Atlantic Coast populations was 62.6 (standard error of the mean equaled 0.08). This sample came from the 1955 year class in the upper Chesapeake Bay. This figure is more than two standard deviations less than the numbers of lateral-line scales estimated from the Gulf Coast fish reported here. The populations of striped bass on the Gulf Coast waters thus appear to be clearly differentiated from those along the Atlantic Coast on the basis of the number of lateral-line scales.

## ACKNOWLEDGMENTS

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## LITERATURE CITED

Hubbs, Carl L., and Karl F. Lagler. 1949. Fishes of the Great Lakes region. Cranbrook Institute of Science, Bull. 26, 186 p.

Raney, Edward C., and Donald P. deSylva. 1953. Racial investigations of the striped bass, *Roccus saxatilis* (Walbaum). J. Wildl. Mgmt. 17: 495–509.

Raney, Edward C., and William S. Woolcott. 1955. Races of the striped bass, "*Roccus saxatilis*" (Walbaum), in southeastern United States. Proc. SE Assoc. Game Fish Comm., p. 60–64.

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# Length—Weight Relationship of Northern Pike, *Esox lucius*, from East Harbor, Ohio

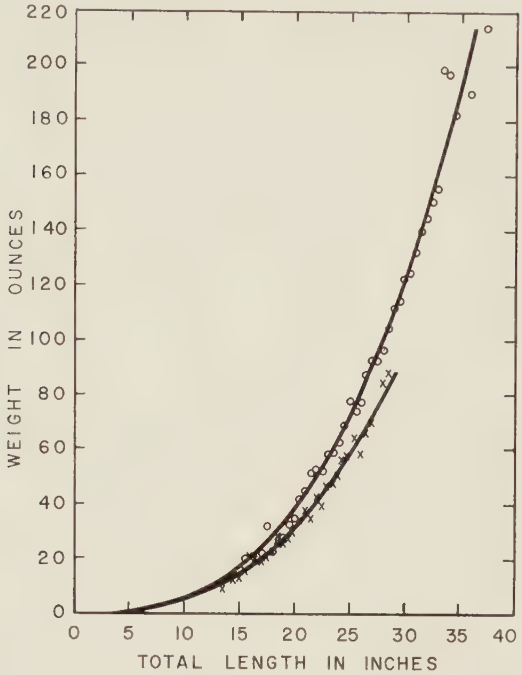

Figure 1.—Length–weight relationship of northern pike collected from East Harbor, Ohio. The mean empirical data for males (crosses) and females (circles) are plotted over curves of the computed equations.

## INTRODUCTION

The northern pike is one of Ohio's largest game fish but is well known to comparatively few anglers. Large numbers of the big fish spawn in the Ohio marshes adjacent to Lake Erie. Movements related to spawning reach a peak in late March or early April. Later the spawning population disperses and is seldom represented in catches by experimental gear or by anglers. The short period of availability was used to obtain life history information in March of 1951 through 1953. No comprehensive length–weight data for the species have previously been published from this area.

East Harbor is a sandspit pond separated from Lake Erie by a large sand bar. Waters and fish populations of the harbor and lake can mix freely through a permanent connecting channel. The larger part of the 850 surface acres of the harbor is normally less than 8 feet deep. A small ditch that drains a limited area of orchard is the only tributary, and the bottom is chiefly fine silt and organic debris. At the time of this study, the harbor contained an abundance of underwater vegetation, mostly *Myriophyllum*. Marshes of cattails, *Typha*, were present along the west and south shores, and an abundance of marginal vegetation was intermittently inundated by seiches generated in Lake Erie by strong winds.

## METHODS AND MATERIALS

Length–weight data were obtained from 218 male and 279 female pike captured in modified fyke nets. Total lengths were measured to the nearest ½ inch and weights were read to the nearest ounce. The females may have been gravid, or partially or completely spent; and any of the pike may have had full or empty stomachs.

## RESULTS AND DISCUSSION

The male northern pike averaged 20.5 inches in length and ranged from 13.5 to 28.5 inches. The conspicuously larger females averaged 26.0 inches and ranged from 15.5 to 37.5 inches. Clark and Steinbach (1959) found the bulk of the population in the 1951–53 period

TABLE 1.—*Comparison of weights of northern pike from East Harbor, Ohio with weights of the species from waters of the northern states listed by Carlander. Total lengths are midpoints of Carlander's length groupings*

| Total length (inches) | Weight in pounds | | |
|---|---|---|---|
| | Range of individual means from Carlander | East Harbor | |
| | | Males | Females |
| 16 | 0.85– 1.10 | 1.04 | 1.23 |
| 19 | 1.50– 2.00 | 1.67 | 2.02 |
| 22 | 2.30– 2.55 | 2.51 | 3.09 |
| 25 | 3.20– 5.00 | 3.58 | 4.49 |
| 28 | 4.31– 5.29 | 4.91 | 6.24 |
| 31 | 6.29– 7.20 | – | 8.38 |
| 34 | 8.10–10.95 | – | 10.95 |
| 37 | 10.50–14.16 | – | 14.06 |

to have been composed of fish 5 years or less in age.

Length–weight relationships were determined for the sexes separately (Figure 1). Least-squares fittings of the logarithms of weights and lengths produced the following equations:

$$\text{Females:} \quad \log W = -2.2008 + 2.9020 \log L$$
$$\text{Males:} \quad \log W = -2.1265 + 2.7788 \log L$$

where $W$ is weight in ounces and $L$ is total length in inches. The difference between the slopes of the two equations was not statistically significant ($F = 3.74$, d.f. $= 1{,}493$, $P > 0.05$). Analysis of covariance consequently was used to remove effects of the unequal length distributions and tests the hypothesis that the adjusted mean weights (logarithms) of the sexes were equal. Rejection of this hypothesis ($F = 249$, d.f. $= 1{,}494$, $P < 0.01$) indicated that the females averaged significantly heavier at the various lengths.

Weights of East Harbor northern pike were compared with weights from Carlander (1950) in Table 1. Males of the present study exceeded Carlander's lower range (sexes combined) values in five of five comparisons. Females of the present study equaled or exceeded Carlander's upper-range values in six of eight comparisons.

## ACKNOWLEDGMENTS

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## LITERATURE CITED

CARLANDER, KENNETH D. 1950. Handbook of freshwater fishery biology. Wm. C. Brown Co., Dubuque, Iowa, 281 p.

CLARK, CLARENCE F., AND FRANK STEINBACH. 1959. Observations on the age and growth of the northern pike, *Esox lucius* L., in East Harbor, Ohio. Ohio J. Sci. 59: 129–134.

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# Delineation of the Layer of Maximum Salinity in Tropical and Subtropical Oceans by Means of Bathythermograph Traces

A conspicuous feature of the vertical salinity distribution in the tropical and subtropical regions of the oceans is a salinity maximum in the upper portion of the thermocline (< 300 m). This feature in the Atlantic Ocean and its relationship to the general thermocline circulation have been investigated by Defant (1936) and Montgomery (1938). For similar analyses in the Pacific or Indian oceans, it would be useful if bathythermograph (BT) data could be used to supplement the relatively scarce salinity data. In this note, a method is described for using the bathythermograph trace to locate the layer within which the salinity maximum will be found in the central North Pacific (10–30° N lat, 140–180° W long).

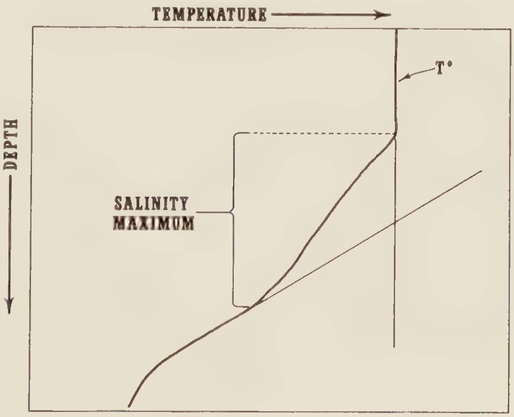

Fig. 1. Schematic diagram illustrating the use of characteristic features of the BT trace to define the layer in which the salinity maximum lies.

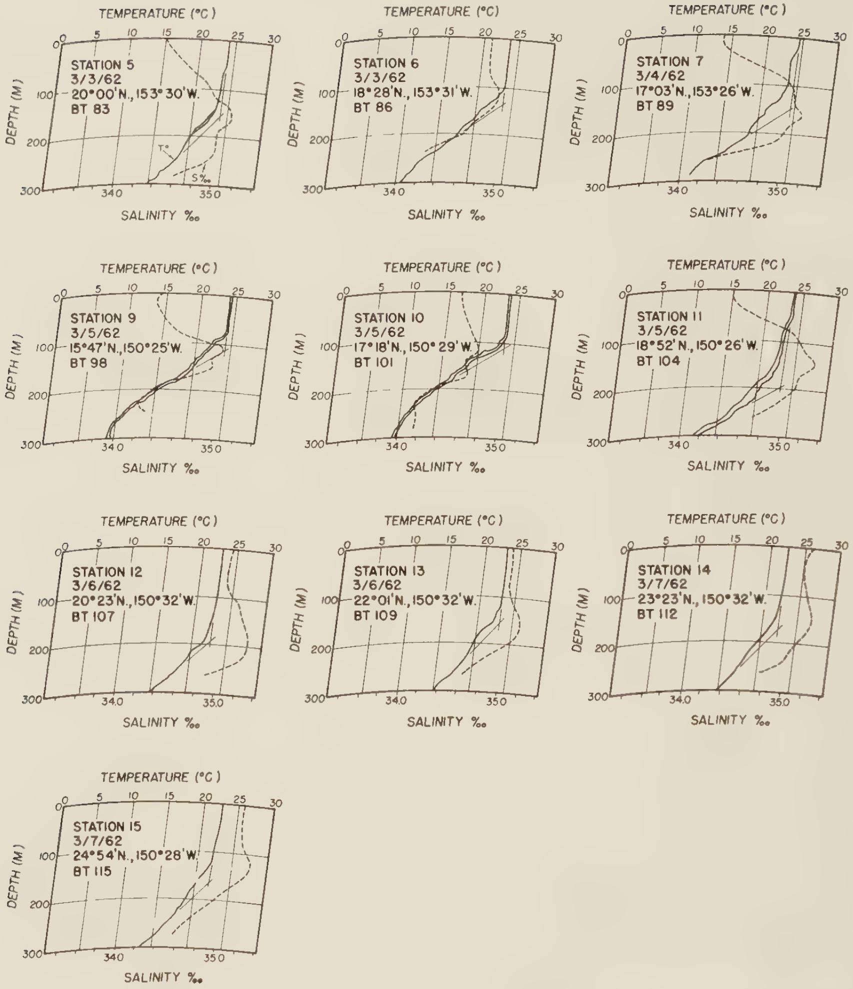

FIG. 2. Bathythermogram-salinity relationships obtained on *Pathfinder* Cruise OPR-421.

The method is shown schematically in Fig. 1. The salinity maximum is found within the layer defined by the two points marked on the BT trace in accordance with the following criteria. The upper limit is denoted by the depth at which the temperature begins to decrease below the temperature value of the mixed layer.[1] The lower limit of the salinity maximum layer is defined by the break in slope of a segment of the BT trace. This segment has the following criteria: 1) it lies in the lower part of the main thermocline; 2) it describes the strongest temperature gradient; 3) it is nearly straight; and 4) when extended, it passes to the right of all portions of the trace lying above it. In addition, it has been found that the depth of the intersection of the line forming the extension of this segment and the temperature of the mixed layer often nearly coincides with the depth of the salinity maximum.

Some applications of the method to BT data obtained by the U.S. Coast and Geodetic Survey vessel *Pathfinder* (Cruise No. OPR-421, March 1962, unpublished data) and the research vessel *Hugh M. Smith*

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[1] The isothermal layer defined by the absence of vertical temperature gradients greater than or equal to 1C per 100 m (Seckel 1962).

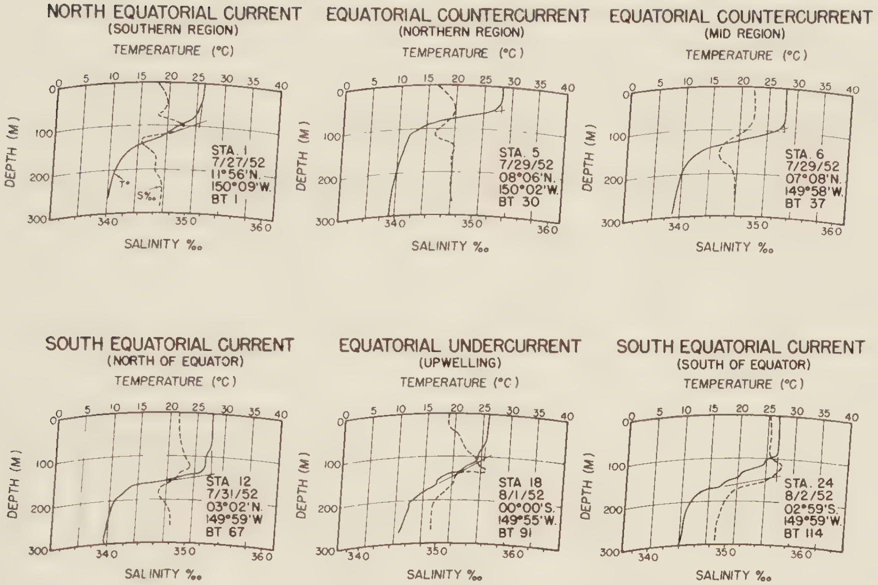

FIG. 3. Bathythermograms and salinity curves for the various current regions crossed on *Hugh M. Smith* Cruise 16.

(Cruise No. 16, July–August 1962), formerly operated by the U.S. Bureau of Commercial Fisheries Biological Laboratory, Honolulu, are shown in Figs. 2 and 3, respectively. Montgomery and Stroup (1962) have reported on the physical oceanography of *Hugh M. Smith* Cruise No. 16. The *Pathfinder* data were obtained along two sections at 150°30′ and 153°30′ W long from 15° to 26° N lat, while the *Hugh M. Smith* data were obtained along one section at 150° W long from 7° S to 12° N lat. These cruises were selected because they are, with the exception of *Hugh M. Smith* Cruise No. 33 (March 1956, unpublished data), the only ones available from the central Pacific Ocean in which the vertical sampling for salinity within the thermocline was detailed enough to test the method. Unfortunately, owing to the poor condition of some of the BT slides obtained on the *Pathfinder* cruise, only 10 of the 15 stations could be evaluated.

From Fig. 2 it can be seen that in each instance the depth layer set off on the temperature-depth curve approximately coincides with the layer in which the observed salinity maximum lies.

Selected BT and salinity curves for the various current regions crossed by *Hugh M. Smith* Cruise No. 16 (Fig. 3) show that: 1) although the shape of the BT curve changes from region to region, the two depth levels define the salinity maximum layer in each case, and 2) the method is applicable to other regions in the Pacific Ocean where the salinity maximum is a feature of the vertical salinity distribution.

Station data and reproductions of BT traces from the Atlantic Ocean (Fuglister 1960) show that, although a remarkable similarity exists between the character of the BT traces taken within the Atlantic and Pacific salinity maximum regions, no definite correlation can be established between

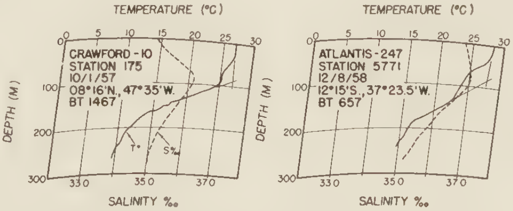

FIG. 4. Bathythermogram-salinity maximum relation from the Atlantic Ocean (bathythermograms reproduced from Fuglister 1960).

the character of the BT curve and the depth of the maximum in the Atlantic because of the lack of detailed salinity observations in the upper 300 m. Fig. 4, however, illustrates two cases in which the results agree with those obtained from the Pacific Ocean, suggesting the applicability of this method to the Atlantic Ocean.

From the examples (Figs. 2, 3, and 4), it is clear that further verification of the method depends on detailed salinity sampling in the upper 300 m and that such sampling should become standard practice in the tropical and subtropical regions of the oceans.

The method provides a valuable tool for use in the tropical and subtropical regions where the subsurface salinity maximum occurs in the upper 300 m. The method should have practical application in: 1) the selection of the sampling interval necessary adequately to define the salinity maximum layer, 2) the interpretation of oceanographic station data, especially as an aid in constructing between-station contours of various properties, 3) the determination of the depths at which to place drogues to evaluate the current structure, and 4) the selection of depths for biological sampling to study the vertical distribution of the biota in relation to the vertical stratification of the thermocline layer.

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## REFERENCES

DEFANT, A. 1936. Die Troposphäre. Deut. Atlantische Exped. *Meteor,* 1925–1927, Wiss. Ergeb. Bd. VI. Teil 1, 3 Lief.: 289–411.

FUGLISTER, F. C. 1960. Atlantic Ocean atlas of temperature and salinity profiles and data from the International Geophysical Year of 1957–1958. The Woods Hole Oceanographic Atlas Series 1, 209 p.

MONTGOMERY, R. B. 1938. Circulation in the upper layers of the southern North Atlantic deduced with use of isentropic analysis. Papers Phys. Oceanog. Meteorol., **6**(2), 55 p.

———, AND E. D. STROUP. 1962. Equatorial waters and currents at 150° W in July–August 1962. Johns Hopkins Oceanog. Studies, 1, 68 p.

SECKEL, G. R. 1962. Atlas of the oceanographic climate of the Hawaiian Islands region. U.S. Fish Wildlife Serv. Fishery Bull., **61**: 371–427.

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# REACTION OF SOME ESTUARINE MOLLUSKS TO ENVIRONMENTAL FACTORS

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# REACTION OF ESTUARINE MOLLUSKS TO SOME ENVIRONMENTAL FACTORS

*Philip A. Butler* *

## INTRODUCTION

For nearly 25 years, this laboratory has been concerned with identifying the environmental factors that permit our commercial species of mollusks to flourish. Studies have been conducted of Santa Rosa Sound, Florida, ~~in~~ and adjacent areas known to be suitable for oysters but which support a relatively small commercial harvest because of the high concentration of natural predators. Santa Rosa Sound is approximately 40 miles long and presents a typical estuarine habitat, although it has two openings into the Gulf of Mexico. Land drainage into the Sound is sufficient to cause marked seasonal and tidal fluctuations in salinity.

In the past, too many biological studies on oysters have been in the nature of crash programs, limited in time and, more often than not, concerned with elucidating problems that had ceased to exist. The convenience of this location and the presence of a permanent staff made it possible to initiate a long-term program to observe the normal range of environmental factors in conjunction with the fluctuations in a natural population of oysters.

The unique facility of estuarine animals to adjust physiologically to more or less drastic environmental changes does not imply that they are equally successful under all conditions, but only that sufficient numbers survive to perpetuate the species. This was well demonstrated about 15 years ago when the upper Chesapeake Bay experienced a protracted period of flooding that extended into the mid-summer months. The oysters become, quite literally, bags of water and contracted perhaps a third in body size. Still, a very few managed to elaborate gametes, there was a late summer spawning, and the brood survived (Butler, 1949).

Our studies in Florida have undertaken the collection of 'routine' data to determine what are normal conditions, and to delineate if possible, changes in the oyster population associated with specific changes in the physical or chemical environment. This report is a brief summary of some of our observations in the past decade, what the environment has offered, and how the oyster and other estuarine animals have responded.

## ENVIRONMENTAL CONDITIONS

There are certain classical parameters used to characterize the estuarine environment and we did not neglect these while searching for more obscure factors. Continuous recordings of fluctuations in water temperature have been maintained since 1947. Water samples have been collected at 4-hour intervals and titrated for total salts with Collier's water sampler (1953) for as long a period. Graphical summaries of these data show the average picture for the years 1951 through 1960 (Figure 1). Figure 2 shows the data for 1959, the year of lowest average salinity, and Figure 3 shows 1954, the year of both highest temperature and highest salinity in the 10-year period. Other specific factors in the environment were scanned from time to time, and these are considered in different sections of this report.

## GROWTH

The most easily measured response of the animal to its surroundings is its growth, and the rate at which it grows may be of fundamental importance in evaluating the environment. One of our earlier studies (Butler, 1952) reported the seasonal percentage increase in length of a small population of oysters. These oysters, collected when less than a millimeter in length at metamorphosis, were observed as individuals for more than 3 years. Table 1 shows their seasonal increments and the change in the pattern of growth as they aged. When juveniles the greatest growth was in the summer. In their second year, there was an emphasis on winter growth, and in their third year almost no growth took place in the warm summer months.

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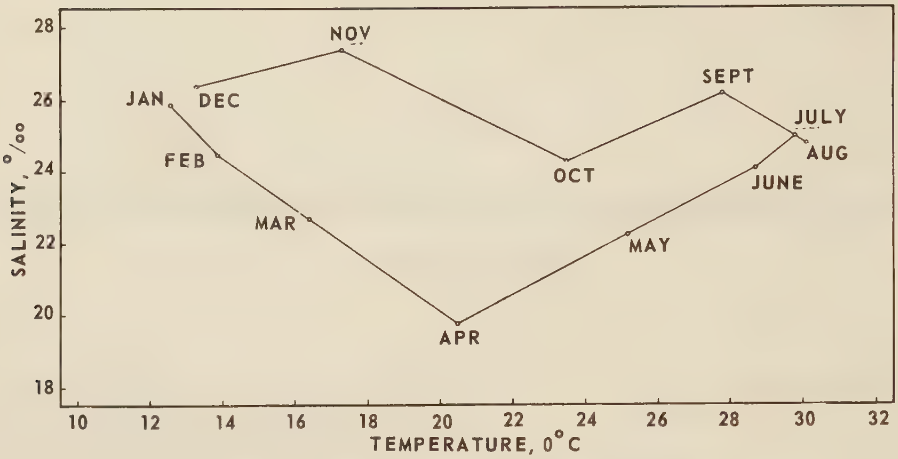

**Figure 1.** Comparison of the monthly water temperature and salinity in Santa Rosa Sound. Data are averages of continuous temperature recordings and titrated salinity samples collected at 4-hour intervals from 1951 through 1960.

Table 1. SEASONAL PERCENTAGE INCREASE IN LENGTH OF A SMALL POPULATION OF OYSTERS

| Age of oysters, years | Percent of annual increment | | |
|---|---|---|---|
| | June-September | October-January | February-May |
| 1 | 46 | 36 | 18 |
| 2 | 14 | 52 | 34 |
| 3 | 11 | 68 | 21 |

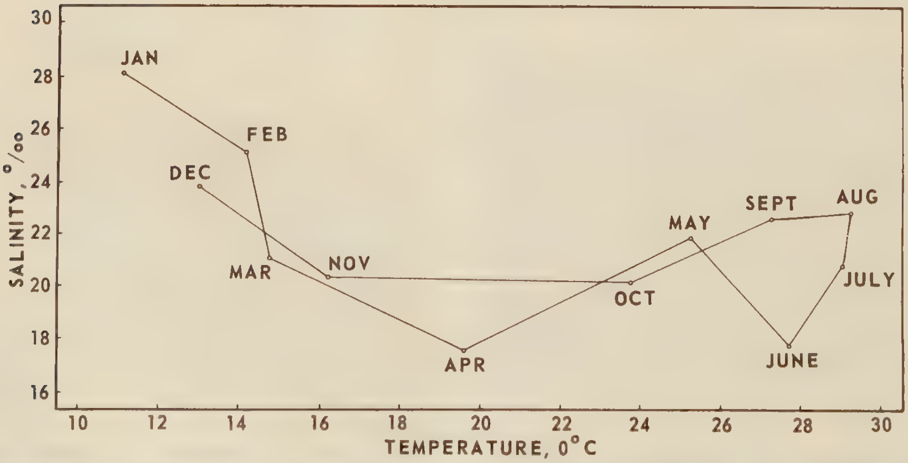

**Figure 2.** Comparison of the monthly water temperature and salinity in Santa Rosa Sound in 1959, the year of lowest average salinity in the 1951 through 1960 period.

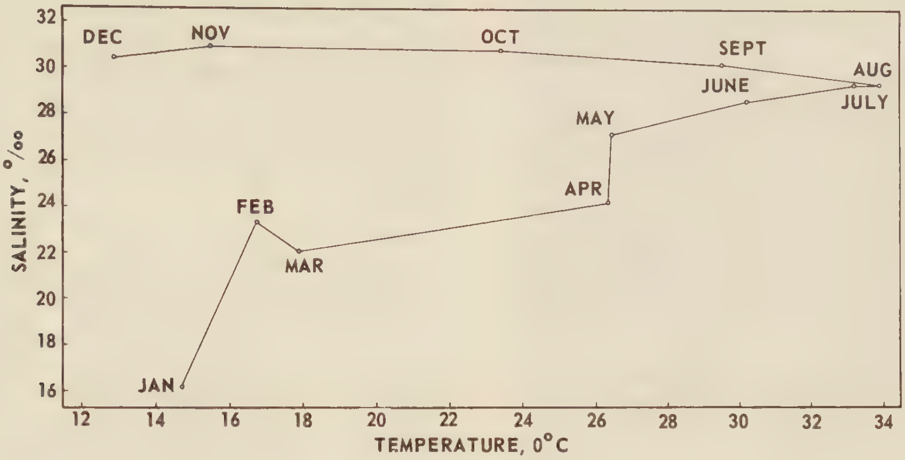

Figure 3. Comparison of the monthly water temperature and salinity in Santa Rosa Sound in 1954, the year of highest average salinity and highest water temperature in the 1951 through 1960 period.

There are several possible explanations for this changed pattern. It is typical of course for metabolic activity to decline with older animals, and it might be suggested that this combined with the demands of summer spawning is sufficient reaseon. In New England waters, however, growth and spawning are not antagonistic in timing, nor is it likely a process of aestivation, as I once assumed, at our summer temperature of about 90°F, since a similar decrease in mid-summer growth is reported by Medcof (1961) in the Canadian oyster at summer temperatures in the neighborhood of 75°F. The important point here is that with the rapid growth of shell in southern oysters it is frequently difficult to age an animal. Growth observations involving experimental animals of the same size but of different year classes may produce paradoxical results.

There are other features of the growth response in mollusks that make this at times an ambiguous criterion of the environment, to say the least, unless considerable background data are available. I should like to cite some examples that bear on this point.

The effect of temperature on growth rates may be seen in some Rhode Island hard clams *(M. mercenaria)* sent to our laboratory in the fall. The effect is dramatically shown in these clams by the white shell (Figure 4), which represents their growth when placed in a clean sand bottom after having been grown in a muddy area. Approximately 75 percent of this new shell was formed during the months of December and January, when had the clams remained in their native habitat they would have been hibernating. This is the simplest and most obvious growth-rate response on the part of the mollusk to one environmental factor, temperature.

A less obvious response is shown in the hard clams depicted in Figure 5. These clams, produced in the Bureau of Commercial Fisheries Biological Laboratory at Milford, Connecticut, by artificial propagation, were sent to Florida when approximately one-quarter inch in diameter. They were reasonably

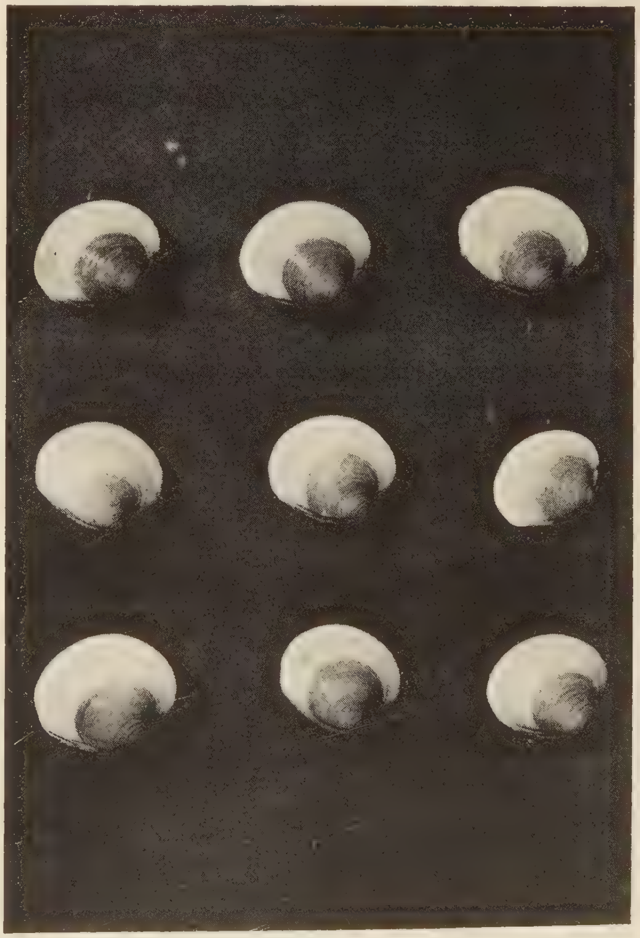

Figure 4. Hard clams, Mercenaria (Venus) mercenaria, transplated from Rhode Island to Florida in the fall were approximately one-half inch in diameter. They doubled in size in the winter months in Santa Rosa Sound when they would normally have been in hibernation.

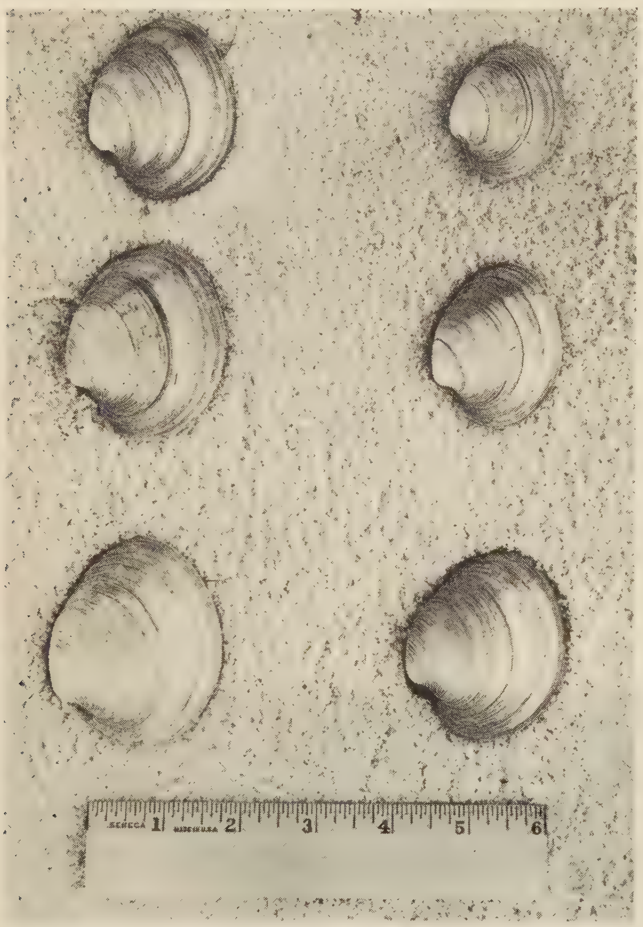

Figure 5. Hard clams, M. mercenaria, derived from a laboratory culture and of uniform size when planted. Individuals, from top to bottom, represent smallest, median, and largest clams recovered from the two locations at end of second year.

uniform in size, but were sorted into two lots whose average lengths were nearly identical. These two lots were planted in protected boxes on either side of the laboratory island and maintained for 2 years. From the biologist's point of view, the two stations were as nearly similar as one could select in the natural environment.

At the end of the 2 years, although mortality had been negligible in the two groups, there were very significant differences in the size range and average size in the two groups. The larger-size group (east) produced 24 percent greater volume of meats when the clams were harvested.

The boxes containing these clams were suspended from the docks at midwater and covered with hardware cloth. As such, they offered a protected niche for a variety of other sand-dwelling forms. Morton's cockle, *Laevigatum mortoni*, was conspicuous at all times. This small clam with inflated valves and usually less than an inch in length is of no commercial importance. At the time the boxes were examined finally, there were ten times as many cockles in the box at the east station and they were on the average 50 percent larger than those in the west box. Similar differences have been observed in the growth and set of oysters at these two stations. A hydrographic survey of these two stations by the Oceanographic Department of A & M College of Texas failed to uncover any physical feature in the environment that would account for these differences in the growth of these mollusks.

Finally, on the question of growth, it is possible to demonstrate a differential response due to an entirely different and in this case an explainable cause. Some years ago, we obtained a supply of seed hard clams derived from reciprocal crosses of pairs of the northern and sourthern variety of quahog. These seed clams were in the size range from 1/16 to 1/8th inch when planted and we maintained them successfully for more than 4 years, side by side in protected boxes hung from the laboratory dock. At the end of that time, the stock of pure *M. mercenaria* was on the average 50 percent longer, and the meat yield of shucked clams was nearly double that of the hybrid stock. Whether this was actually a hybrid cross has been questioned, but this is immaterial to the point that they were of controlled parentage. Each group of clams had been derived from separate gene pools and had shown distinctly different growth characteristics in identical biological environments.

Knowing these different growth responses exist, we are impressed with the necessity of knowing the complete background of test animals before hazarding a guess as to the reasons for their observed growth rates in any particular situation. We must know the age of the animal, we must know its genetic background, and we must be assured of the similarity of our test sites before we can suggest that this or that is truly a response to an environmental factor.

## REPRODUCTION

The unreliability of random growth-studies for assaying the suitability of the environment to mollusks led us to consider the possibility of using the seasonal gonad cycle in oysters as an index of well-being. Small populations of oysters were kept in protected trays, specimens were sacrificed at monthly intervals, and the activity of the gonads was evaluated on an arbitrary arithmetic scale (Butler, 1949). We were fortunate in having data on the gonad cycle of oysters growing in Chesapeaka Bay, as well as having some Chesapeaka Bay oysters that had been transplanted to Florida, for comparison with the native oyster. In general, the gonad cycle was the same for the three groups with the exception of the timing (Butler, 1955). The Chesapeake Bay oysters, after 1 year of adjustment in Florida waters, started spawning at a temperature level 5°C above that of their parent stock, and reached a stage of mass spawning also at a 5°C higher temperature level. In addition, their spawning period was extended from the usual 3-1/2 to 5 months. Their reproductive activity was indistinguishable from the native Florida oysters. Figure 6 compares the timing and level of gonad activity in the two stocks of oysters at each location.

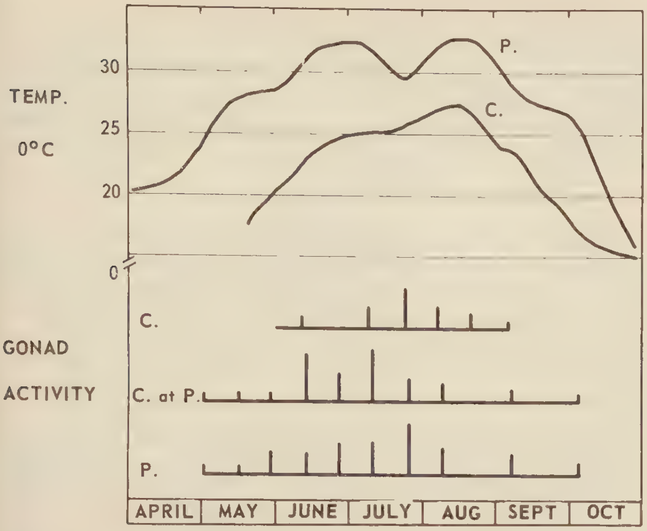

Figure 6. Comparison of reproductive cycle in two stocks of oysters, in which spawning was arbitrarily considered as the maximum level of activity: Chesapeake oysters (C) growing in Chesapeake Bay; Chesapeake oysters (C at P) after growing for two years in Santa Rosa Sound; and (P) Florida native oysters growing in Santa Rosa Sound. The horizontal bars indicate the duration of the spawning periods while the vertical bars, ranging from about 20 to 90 percent, indicate the number of spawners in each sample.

These results suggest that the oyster's reproductive activity is regulated primarily by changing temperature levels rather than a hereditary response to a specific temperature threshold. Examination of our decade of spatfall records in Santa Rosa Sound indicates that spawning is unitiated following a 5°C temperature rise within a 30-day period. The actual onset of spawning has occurred at temperatures ranging from 18 to 27°C, and varies in time from early March to mid-May. In this area at least, the fact that oyster spawning has been initiated tells you essentially nothing about the time of the year or the temperature of the water.

It might be expected that if northern oysters accommodate to the water temperature regimen in the south the reverse might be true. There are numerous citations, however, of the failure of southern animals to spawn when transplanted to more northern latitudes. It is important to note that the response of the oysters here is apparently not to temperature *per se* but to a relative change in temperature. This may account for their failure to spawn in northern waters, although this failure is usually explained on the basis of a particular threshold value, and inferentially, physiological speciation.

Variations in the onset of spatfall from year to year have been mentioned briefly. The timing of the spatfall and the amount of successful set are of particular concern to the commercial oyster grower. They are also of interest to the biologist in considering the relationship of species success and specific factors in the environment. The study of spatfall has been a favorite tool because of the relative ease in obtaining objective data that are susceptible to statistical analysis.

At our laboratory, squares of cement-board offering 100 square centimeters of surface are suspended from the dock and changed at 7-day intervals (Figure 7). The number of sedentary organisms per square centimeter is then calculated by counting a varying percentage of the surface depending on the numbers of organisms present. It is of interest that in more than a decade of such observations, we have always had at least one macroscopic, sedentary animal on the plate by the end of the week (Butler, 1954).

Presumably the amount of spatfall on these plates is one measure of the adult oyster's response to the environment; while this is true, it is by no means the entire story. I am not considering at this point areas in which from time to time the annual set is a complete failure. In Santa Rosa Sound, the annual set is normally so heavy as to be objectionable from the commercial point of view. The density of the spatfall is greatly influenced not only by the amount of spawn produced by the adults but also by events in the pelagic life of the larvae. Their numbers may be affected seriously by sudden hydrographic changes, by disease,

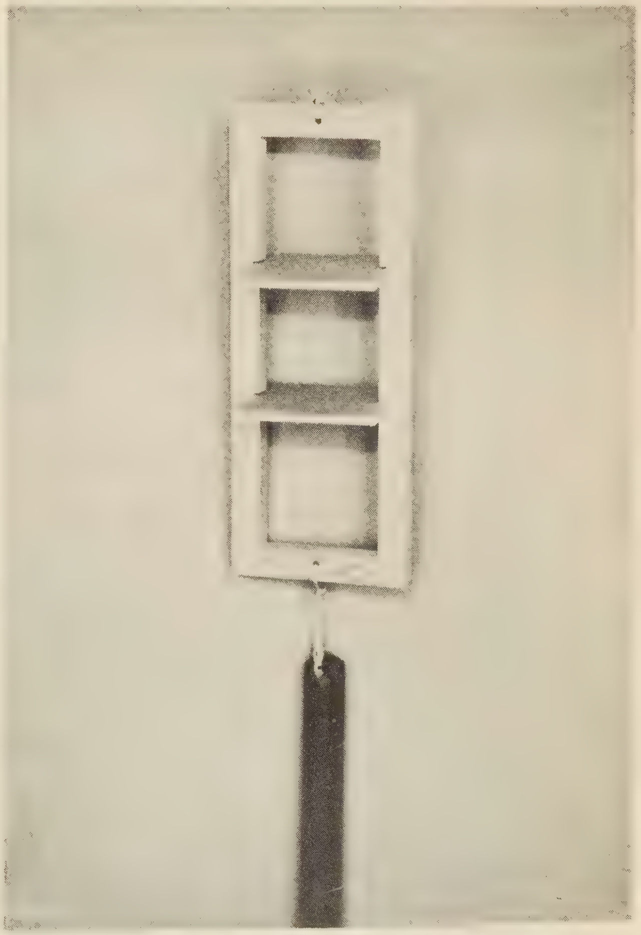

Figure 7. Weighted wooden frame supporting four-inch square cement-board plates used to collect natural oyster set.

or by the relative success of some predator. For these and other reasons, the record of one year of spatfall in a particular environment may be of little value.

A summary of a decade of records of spatfall in Santa Rosa Sound is shown in Figure 8. A line graph of the averaged data indicates a not unpredictable distribution of the set thruout the summer months, starting and ending at low levels and with an early summer peaking of the set. Examination of the records for individual years, however, immediately reveals the error in this picture. The solid area in each year's record indicates the period during which 50 percent of the total set for the year was collected on the plates. This period varied in length from 2 to 6 weeks and more importantly varied from month to month during the summer, seemingly at random. There was no apparent relationship between the timing and the total set in any particular year. The accumulated seasonal set varied from 13 to more than 90 spat per square centimeter in the period under consideration, and in other years, has been nearly double this amount. Oyster and clam larvae have relatively short pelagic lives, and Davis (1958) has shown that they are far less tolerant than adults to changing hydrographic conditions. Consequently, these spatfall data reflect the effect of the environment on the larvae rather than on the mature oyster.

We know too, from long experience, that our estimates of the total weekly set can vary greatly depending on the skill of the technician in handling the cultch plates. Variations in angle of plate, level in the water, intensity of barnacle set and other factors have predictable effects on the successful set of oysters on the plates.

We have had at least one clear demonstration of the drastic effect that environmental factors may have on the intensity of set, and the fact that they exert their influence on the larvae rather than on the adult. On August 30, 1950, this area experienced a severe tropical storm that brought more than 7 inches of rainfall and a storm tide of 5.5 feet. Figure 9 graphically portrays the change in oyster set on artificial cultch during the period of this storm, and in adjacent years when no such storm occurred. It is clear here that the increase in set has been entirely the result of larval survival and not production, since the increase was limited to the period of larval life of the brood and occurred before a new brood could have matured.

Larvae of other sedentary forms as well as the total plankton mass were similarly affected; table 2 shows the relative changes in some setting rates from the period one week before the storm to one week afterwards.

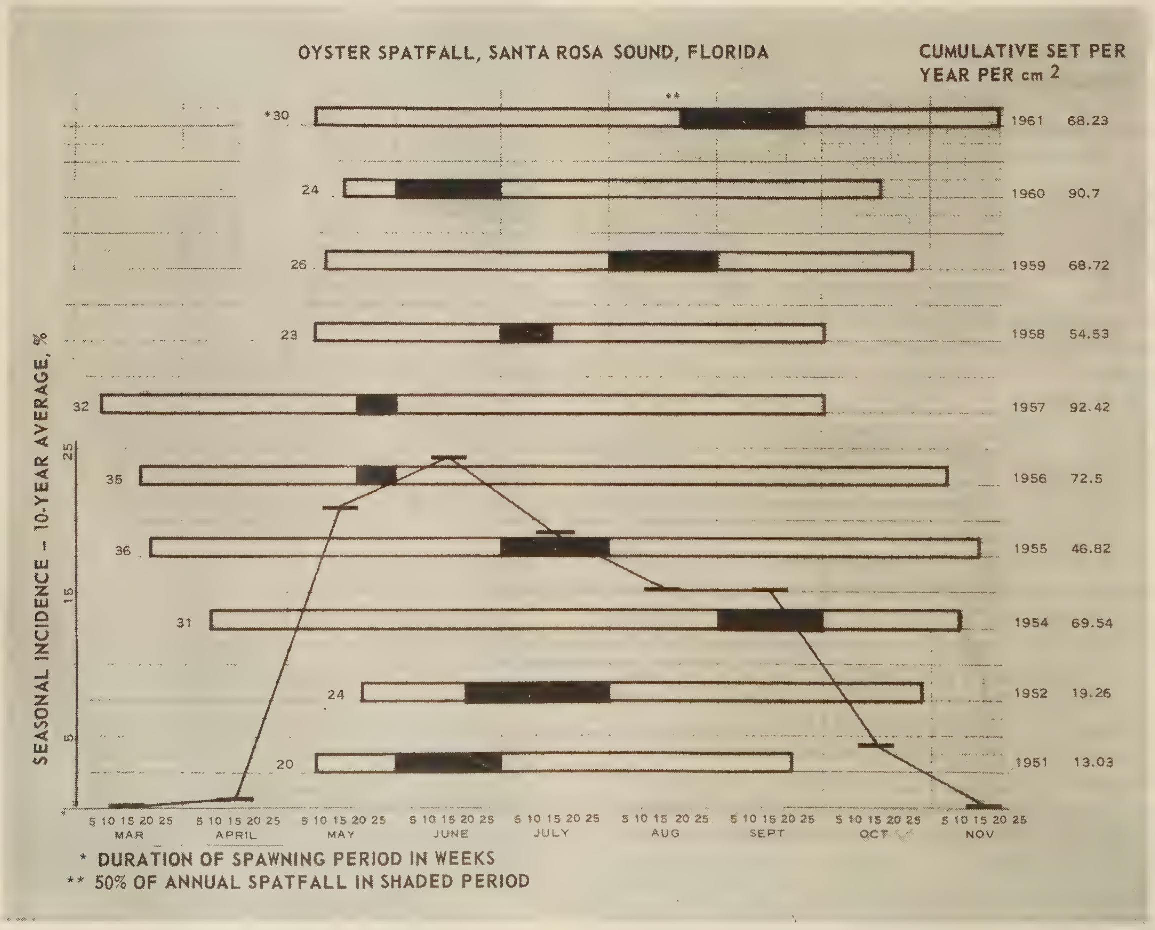

Figure 8. Seasonal and cyclic occurrence of oyster spat on artificial plates, which were changed at seven-day intervals. Data for 1953 incomplete and not included.

Table 2. EFFECT OF STORM ON SETTING OF SEDENTARY ANIMALS

| | Incidence of organisms per cm$^2$ per week | | |
|---|---|---|---|
| | 1 week before storm | 1 week after storm | |
| Barnacle | 0.3 | 170.6 | 568x |
| Oyster | 1.1 | 73.0 | 67x |
| Mussel | 0.1 | 3.2 | 32x |
| Bryozoa | 0.1 | 2.1 | 21x |
| Plankton M1/100 1 | 0.9 | 5.0 | 5x |

In 1953, this area experienced another tropical storm, which was similar in all obvious factors except that the direction of the wind was different and there was no accompanying storm tide. Following this storm there was no observed increase in the set of plankton organisms.

In 1955 a tropical storm occurred in the New England area accompanied by high tides; Dr. Loosanoff (1955) reported that more mature oyster larvae were observed than ever before and the set was greater than in the preceding 11 years. The following year, after two tropical storms in New England, he reported that they had experienced the longest setting period in their 20 years of observations (Loosanoff, 1956).

These observations suggest that high waters had leached from the neighboring marshlands some trace elements or simple nutrients that has greatly enriched the estuarine waters. This enrichment caused increased phytoplankton productivity and, in turn, resulted in greater survival of the larval broods.

## NUTRITION

The differential in molluscan growth and set on the east and west sides of the laboratory island in Santa Rosa Sound has been a subject for our investigation for some years. We have pursued such environmental factors as temperature, salinity, pH, nutrient salts, dissolved copper, chlorophyll and other plankton pigments, total plankton, turbidity, currents, and others, without identifying any causal relationships. More than a decade ago, the existence in this area of natural substances in sea water responding to chemical tests for carbohydrates was reported by Collier et al. (1950). In the course of an extensive testing program, they found that concentration of this material was positively correlated with the pumping activity of oysters; usually, oysters did not pump during the winter months when carbohydrate levels were less than approximately 4 mg/1, nor in the summer at levels much below 6 mg/1. They postulated a causal relationship (Collier et al., 1953).

We re-examined this situation utilizing the same basic techniques and much of the same equipment,

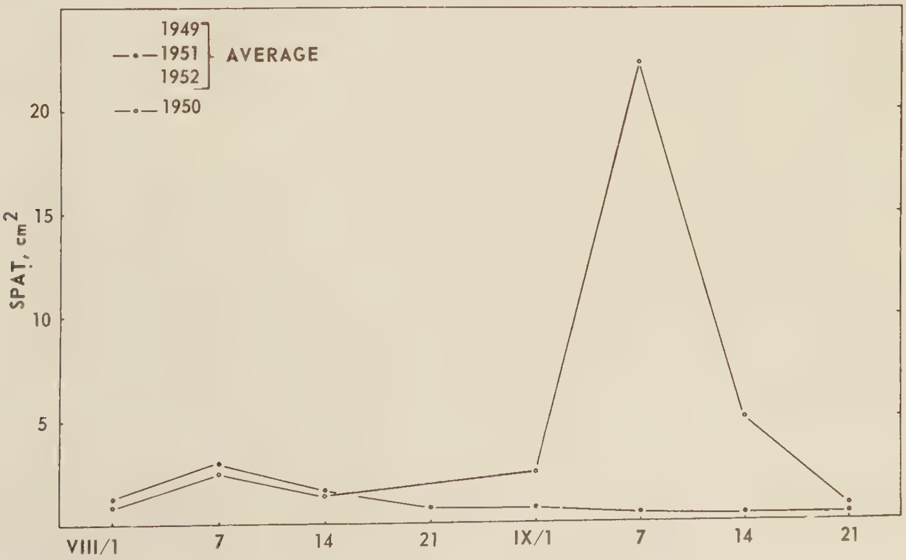

Figure 9. Weekly setting rate of oysters in Santa Rosa Sound in 'average' years, and following the tropical storm of August 30, 1950.

in the hope this might explain our east-west station differential (Butler et al., 1959). We found carbohydrate concentrations surprisingly low as compared to data obtained earlier in the identical geographical area; in fact, considerably lower than what has been reported as minimal threshold values for oyster pumping activity. Consequently, we undertook a series of continuing observations to re-examine the putative relationship between carbohydrate concentration and oyster pumping activity.

Oysters were individually confined by means of a plastic box and rubber dam (Figure 10) so that when the box was attached to the inside of a larger tank the inhalent side of the oyster was exposed to the common water supply, the exhalent side was separated and the water pumped by each oyster could be metered and recorded on a kymograph. Movement of the upper shell was transmitted to the kymograph by means of a thread. Experiments were set up so that the activity patterns of ten oysters were recorded simultaneously and hourly samples of water from the common source were taken for carbohydrate analysis.

Pumping of water by the oyster while not quantitatively related to food intake is ordinarily a prerequisite to feeding. Included here under the general heading of nutri~~ent~~tion are various observations on water pumping, shell movement and shell deposition.

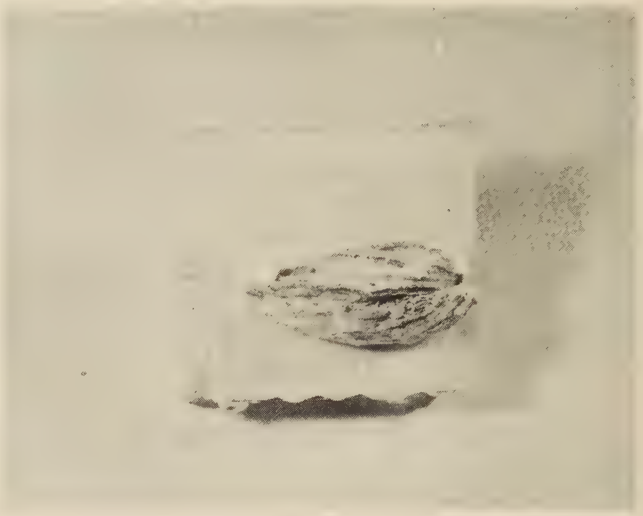

Figure 10. Oyster attached to plastic frame with rubber dam separating inhalent (dorsal) from exhalent side. This makes possible recording the amount of water pumped; thread attached to upper valve transmits shell movement to kymograph.

Figure 11 illustrates a section of a typical kymograph record of the simultaneous activity of three oysters in the same aquarium over a period of about 3 hours. The top line 'P' of oyster number 1 records the number of times the effluent water bucket was tripped. In this case, pumping appears to be relatively uniform, although the rate varies from about 30 to 50 units per hour or the equivalent of 8 to 12 liters per hour. We are not interested here, however, in the exact quantity of water pumped, but rather in the regularity of the pumping activity. The second line 'S' shows the typically irregular movement of the right valve as the oyster pumps. The vertical lines

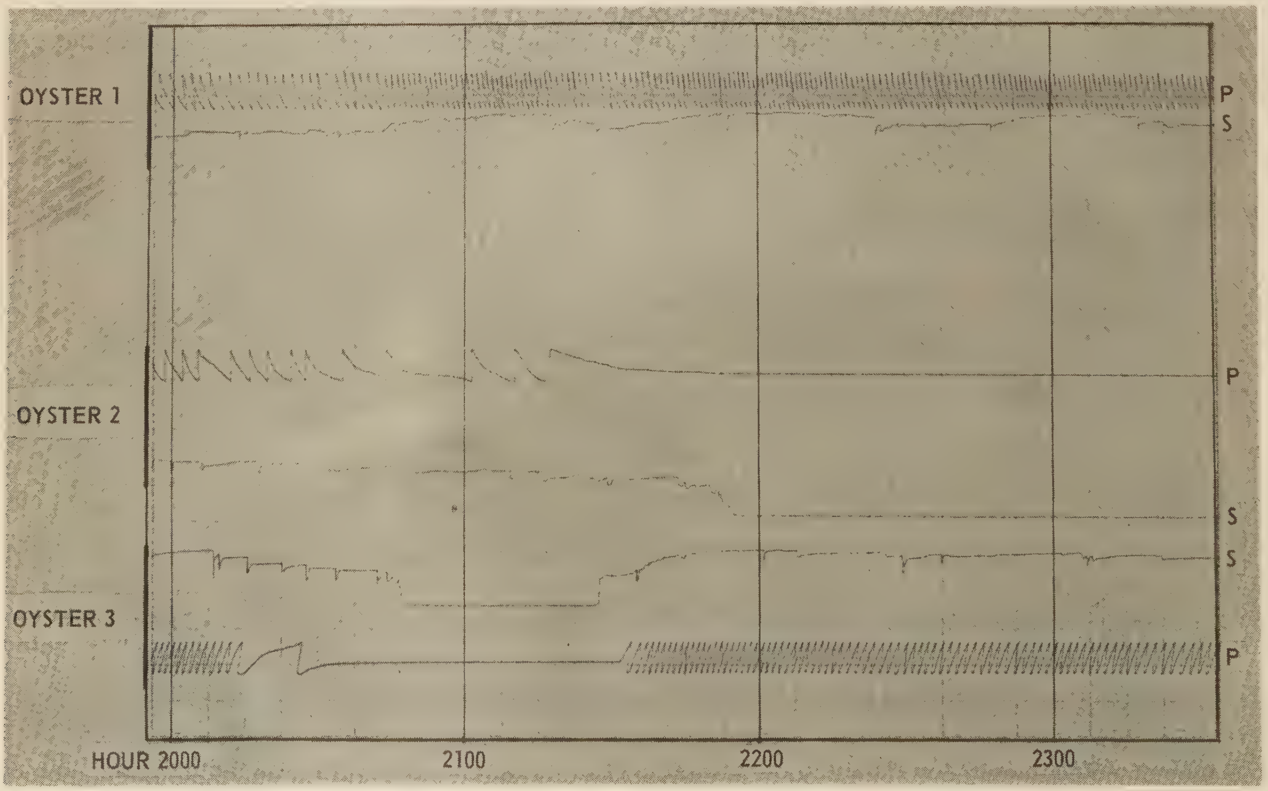

Figure 11. Kymograph record of water pumped (P) and shell movement (S) of three oysters in same aquarium showing individual variations in response to common environment.

indicate an amplitude of 2 to 3 mms in shell movement. In this period the oyster did not close its valves completely.

The record of the second oyster obviously shows a quite different activity. The 'P' line indicates a decreasing rate of activity for the first hour and finally a cessation of pumping. The shell movement line indicates a progressive series of snap closures; each time the valves open somewhat less, and finally, just before 2200, the oyster closed completely.

The third record shows a similar interruption in pumping and shell closure, but after an hour the oyster opened abruptly and continued pumping at its 'normal' rate.

These records illustrate well the individuality of oysters in responding to factors in a common environment. It is apparent that at about 2000 hours there was some external factor, which all three detected but responded to in a different manner.

Our observations in this experiment consisted of searching the kymograph record for each 24-hour period to locate times in which the oysters as a group exhibited normal activity, followed by a progressive slowing down, and then a return to the normal rate of pumping. Only the water samples collected during these stages were analyzed for carbohydrate concentrations. In all, 70 occasions were found that satisfied all of the requirements for our testing conditions. The results of these analyses are shown in Table 3. Carbohydrate concentrations were determined when the oyster was pumping at a normal or regular rate, and then again an hour later when the kymograph record showed that its pumping was slowing down markedly. The data of the initial carbohydrate concentrations were arbitrarily grouped into three ranges. At the lowest initial range of 0-0.9 mg/1 the table ~~graph~~ shows that of the 24 occasions when the pumping rate decreased, the carbohydrate concentration decreased 10 times, stayed the same 3 times, and increased 11 times. Data for the other ranges are similar and, in sum, out of the 70 periods, changing carbohydrate concentrations were correlated with decreased pumping negatively 41 percent of the time, positively 40 percent, and showed no change 19 percent of the time.

Table 3. CHANGES IN SEA-WATER 'CARBOHYDRATE' CONCENTRATION WHEN OYSTERS WERE OBSERVED TO BE DECREASING THEIR PUMPING ACTIVITY

| Initial concentration of 'carbohydrate' mg/liter | Direction of change and number of observations | | |
|---|---|---|---|
| | Decrease | Static | Increase |
| 0.0 - 0.9 | 10 | 3 | 11 |
| 1.0 - 1.9 | 16 | 10 | 17 |
| 2.0 - 4.3 | 2 | 0 | 1 |

The second method we used to correlate oyster pumping activity with carbohydrate concentration was to estimate the number of hours of the day when the oyster was actively pumping and compare this with the level of carbohydrate in a composite sample of water for the 24-hour period. The lengths of these periods were tabulated on a percentage basis, and plotted against the carbohydrate levels (Figure 12).

Since in our area oysters may show a differential pumping activity that is apparently correlated with temperature, the data are grouped at two different temperature levels. In the range of 10 to 20°C, i.e., from January through March, daily pumping activity occupied from 65 to 100 percent of the time. Carbohydrate concentrations were all below 4 mg/1. Records of many periods of almost continuous activity were obtained when carbohydrate concentrations were between 0.0 to 0.9 mg/1. A decade earlier, almost no pumping activity was observed at carbohydrate levels below 4 mg/1 in this temperature range.

At temperatures between 20 and 30°C, market size oysters may be expected to show less pumping activity; in this experiment activity ranged from 25 to 95 percent. With minor exceptions, all of this pumping took place at carbohydrate levels below 2.0 mg/1. Collier found at these temperatures it was necessary to have a carbohydrate concentration of approximately 6 mg/1 before pumping was initiated. Figure 12 indicates little if any correlation between increased pumping activity and increased levels of carbohydrate at either temperature range; nor does there appear to be any minimal threshold below which oysters were inactive.

I am reporting this material in some detail because it is important to note that what at one time appeared to be a clear-cut relationship between oyster behavior and a particular parameter of the environment is now open to a different interpretation. This is not to suggest that in the earlier work the activity of oysters was not correlated with carbohydrate concentrations, but rather that at that time oyster activity and carbohydrates were both related to some other and still unknown environmental factor.

Numerous workers have noted the characteristic shell movements of oysters under varying internal and external environmental conditions. The spawning reaction of ripe males, for example, is easily stimulated by appropriate temperature changes and, in turn, the reaction of ripe females to sperm suspension or to temperature is clearly defined (Galtsoff, 1961). A similar group response is illustrated in Figure 13, which excerpts a 5-hour record of two mature oysters in a common aquarium. The shell movement lines indicate a series of snap closures of the shell at approximately hourly intervals. These partial closures occurred at the rate of about two a minute, and had no effect on the pumping rate as seen by the regularity of the pumping record. This response has been noted on numerous occasions and we at first thought it indicated spawning behavior. Later, it was observed during the winter months and commonly a majority of the animals in a community aquarium showed the reaction simultaneously. The reason for this reaction is unknown but it typifies the oysters' sensitivity to apparently subtle factors.

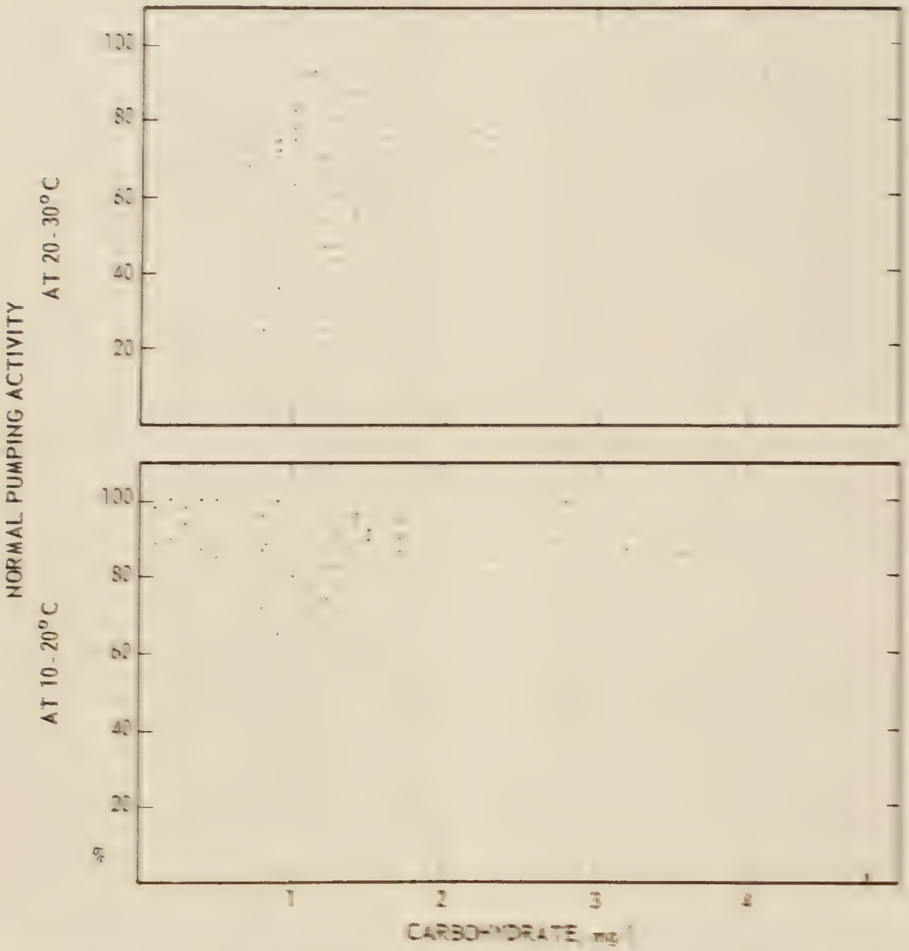

Figure 12. Normal pumping activity (i.e., percent of time oyster was open and pumping) compared to concentration of natural 'carbohydrate' at two temperature ranges. Each dot represents the level of activity of one oyster for one day at the indicated temperature and level of 'carbohydrate'.

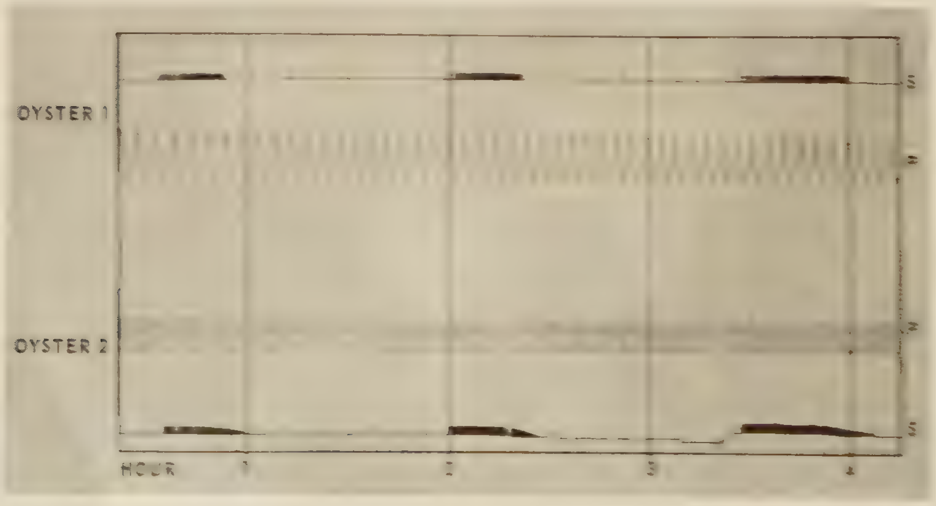

Figure 13. Kymograph record of shell movement (S) and pumping rate (P) of two oysters in a common aquarium. The (S) lines indicate their simultaneous response to some external factor at approximately hourly intervals.

The recording of shell movement and pumping activity of oysters provides a convenient tool for the evaluation of pollutants added experimentally to the environment. In some preliminary work, we found many of the common argricultural pesticides had a marked deleterious action on oysters at concentrations ranging from 0.01 to 1.0 ppm in running sea water (Butler et al., 1960). The number of hours per day that the oyster was open and pumping steadily decreased after a week of continuous exposure to a noxious chemical. For example, after 5 weeks of continuous exposure to Dieldrin at 0.1 ppm the daily activity of exposed oysters was only half that of controls (Figure 14). The graph shows clearly, too, that after removal to clean water there was a fairly rapid recovery.

This reaction of the oyster to its environment is clear-cut and provides useful data. The technique, however, is tedious and time consuming. It is more expedient under the same experimental conditions, simply to measure the rate of deposition of new shell in juvenile oysters. In Figure 14, these data are indicated as percent growth. It is apparent in the graph that there is an immediate decrease in this shell deposition in the experimental oysters, whereas decreases in percent pumping activity of mature oysters were not apparent until after the second week of expousre to the pollutant. The recovery in the rate of shell deposition follows the same pattern as the return to normal pumping activity. It is of interest to note the simultaneous response in activity and shell deposition in both experimental and control oysters to the relatively small temperature fluctuation during the terminal 3 weeks.

Linear growth of the oyster does not proceed at a uniform rate under uniform conditions. There is an initial increase in the terminal deposition of shell followed by a period during which this new shell is thickened by internal deposits. During this stage there may be no increase in length. In order to avoid misinterpretation of these length increases, the shell of the oyster is filed until all new or thin shell has been removed; the oyster meats then occupy all of the available space. Under these conditions, the oyster has no alternative in growing except to deposit new shell at the posterior end. Figure 15 shows one of these oysters with the shell newly filed, and deposits of new shell at the end of 2 and 7 days. Under average conditions, shell deposits are made at the rate of approximately 4 millimeters per week in control oysters. The average amount of new shell deposited by oysters under comparable conditions is uniform and statistically valid even for small groups. We are finding it a most useful criterion for evaluating the relative toxicity of a large series of pesticide chemicals and determining at what concentrations these chemicals become physiologically unacceptable to the oyster.

It is apparent from these data on the toxic quality of agricultural pesticides that mollusks exhibit at least three types of reactions. In the first type, as the concentration of the pollutant is decreased, by a factor of ten for example, the rate of shell deposition gradually increases to that of the controls. This may be noted with such chemicals as endrin, aldrin and heptachlor.

In the second type, a given concentration may cause a marked decrease in shell deposition, yet

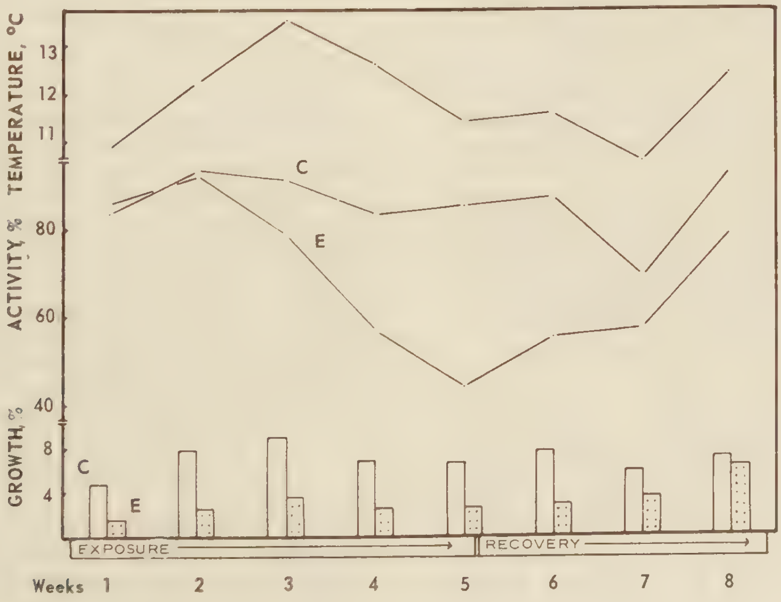

Figure 14. Pumping activity of mature oysters in running sea water exposed to a Dieldrim concentration of 0.1 ppm for 5 weeks, and for the succeeding 3 weeks in unpolluted water. The growth rate of juvenile oysters held in the same tanks (E) is compared to control juveniles (C).

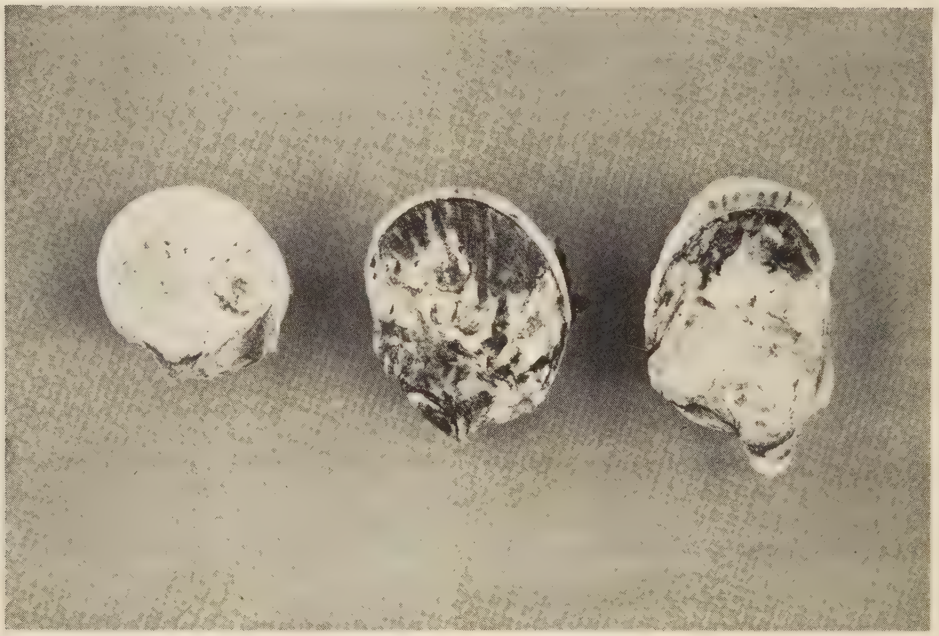

Figure 15. Shell deposition on 1-½-in. oysters. Control on left; after 2 days (middle); and after 7 days (right).

dilution by a factor of ten renders it apparently harmless. It seems that in a wide variety of pesticides, including dieldrin, Kepone, and parathion, there is a fairly sharp threshold level of toxicity.

In this third type, our data are still incomplete. Small hard clams are being exposed over relatively long periods of time to four chemical pollutants at concentrations from 100 to 1000 times more dilute than levels found irritating to small oysters. In the first 3 months, all groups grew as well as controls and showed similar activity and mortalities. In the fourth month, clams exposed to one part per billion of DDT have experienced a sudden mortality of approximately 30 percent. They are sluggish when uncovered and fail to bury themselves in the sand. It is possible in this case, that there has been either an accumulation of the toxicant to lethal levels within the clam or else a loss of resistance on the part of the clam. In either case it indicates the possibility of a build-up, over long periods, of low concentrations of pollutants in an estuary until they finally become disastrous to molluscan populations.

## CONCLUSION

A great deal of work remains to be done in identifying the reactions of mollusks to specific natural factors in the environment and to man-made pollutants. It is obvious that variations in environmental parameters may become limiting factors, as they approach extremes. Thus, high or low salinity controls the expansion of oyster populations at either end of the estuary. Similarly, low temperatures suppress spawning ~~the~~ and population expansion of the eastern oyster when transplanted to the Pacific coast.

Over a broad intermediate range of environmental conditions, however, the survival of molluscan populations is a result of highly complex and inter-related attitudes toward individual factors. Apparently simple responses, such as growth rates, may be greatly influenced by age, or heredity, or nutrient salts and vitamins naturally present in the environment in only trace amounts.

Although acute toxic levels of natural and man-made pollutants are quite simple to demonstrate, the effects of low levels of toxicants are much more obscure, and disasterous changes in productivity levels might occur without significant mortality. Our ability to delineate the individual factors that are deleterious to estuarine forms will determine in large measure our success in preserving this part of the marine environment, which is so sensitive to pollution. Only by understanding the role of both beneficial and harmful factors will we be able to reach maximum utilization of our estuaries for both biological and industrial purposes.

## ACKNOWLEDGEMENT

It is a privilege to acknowledge the assistance and cooperation of the entire laboratory staff whose efforts during the past decade have made this summary possible.

## REFERENCES

Butler, Philip A., 1949. Gametogenesis in the oyster under conditions of depressed salinity. Biol. Bull., 96: 263-269.

Butler, Philip A., 1952. Seasonal growth of oysters (C. virginica) in Florida. Proc. Natl. Shelfish. Assoc., 43: 188-191.

Butler, Philip A., 1954. Selective setting of oyster larvae on artificial cultch. Proc. Natl. Shelfish. Assoc., 45: 95-105.

Butler, Philip A., 1955. Reproductive cycle in native and transplanted oysters. Proc. Natl. Shellfish. Assoc., 46: 75.

Butler, Philip A., and Alfred J. Wilson, Jr. 1959. Relation of oyster pumping to the carbohydrate concentration of sea water. Convention Address, Natl. Shellfish. Assoc.

Butler, Philip A., Alfred J. Wilson, Jr., and Alan J. Rick. 1960. Effect of pesticides on oysters. Proc. Natl. Shellfish. Assoc., 51: 23-32.

Collier, Albert, Sammy M. Ray, and Wayne Magnitzky. 1950. A preliminary note on naturally occurring organic substances in sea water affecting the feeding of oysters. Science, 111: 151-152.

Collier, Albert, S.M. Ray, A.M. Magnitzky and Joe O. Bell. 1953. Effect of dissolved organic substances on oysters. Fish. Bull. USFWS, 54: 167-185.

Davis, H. C. 1958. Survival and growth of clam and oyster larvae at different salinities. Biol. Bull., 114: 296-307.

Galtsoff, Paul S., 1961. Physiology of reproduction in molluscs. Am. Zool., 1: 273-289.

Loosanoff, V.L., 1955. Milford Laboratory Bulletin No. 10. 2pp. mimeo.

Loosanoff, V. L., 1956. Milford Laboratory Bulletin No. 11. 4 pp. mimeo.

Medcof, J.C., 1961. Oyster farming in the Maritimes. Fisheries Res. Brd. Canada, Bull. No. 131, pp. 1-158.

## DISCUSSION

The discussion following the formal presentations immediately centered upon our lack of basic knowledge of the effects of pollution on the estuarine environment. Considerable emphasis was placed upon the need for an investigator to know his experimental animals thoroughly before attempting to interpret the results. The work reported to this time has demonstrated the great diversity of responses that may be expected between or among animal groups and life history stages. Delayed or indirect effects often turn out to be the most important feature uncovered by a given investigation. The subtlety of such responses brought up the objection to "kill - no kill" as parameters in toxicological research. There was general agreement that we should work on the more subtle, physiological effects of sub-lethal toxicity. Comments from the floor supported the participants' views in pointing out the need for basic studies on environmental requirements of larval development since this is often the most sensitive stage in the life history of estuarine animals.

Dr. Carraker concluded the session with a summary of the presentations and suggested that, in selecting or determining the range of parameters which are suitable for the environment in a particular estuary or embayment, the following should be attempted:

1) A systematic study of the dominant species present, so that we have a good taxonomic base upon which to build.

2) A field, ecological-life history and horizontal distribution and density study of the major species.

3) Rear animals in the laboratory under controlled conditions, and subject them to changes in these parameters, one by one, then in combination and then in fluctuation, to try to simulate the complex which exists in the environment.

4) Lastly, to bring to our aid, mathematics and computers to help make a proper interpretation of these conditions.

# A RECENT OCCURRENCE OF THERMAL STRATIFICATION AND LOW DISSOLVED OXYGEN IN WESTERN LAKE ERIE[1]

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## ABSTRACT

Instances of thermal stratification have been detected only occasionally in western Lake Erie during the past 40 years, but when it does occur it is of considerable importance because of associated dissolved oxygen (DO) depletion in the hypolimnion. Data collected in June of 1963 give an indication of the meteorological conditions necessary to produce this thermal stratification. These conditions are: daily wind speed of less than 3.1 m/sec (7 mph); highest wind speed of less than 6.7 m/sec (15 mph); and an average daily temperature of more than 18.5 C for approximately 5 consecutive days. Weather records for Sandusky, Ohio, show these conditions to have occurred on 33 separate occasions between 1953 and 1963. These data suggest stable thermal stratification occurs more frequently than heretofore suspected. The 1963 data also show that in only 5 days of stratification DO in the hypolimnion was reduced to less than 3 ppm, whereas 28 days were required in 1953. This increased rate of DO depletion is probably due to an increase in the oxygen demand of the bottom sediments in recent years.

The Western basin of Lake Erie is a shallow, essentially estuarine area with a mean depth of only 7.3 m and a surface area of 3276 km.$^2$ Two peninsulas and a cluster of islands partially separate it from the main body of the lake. A long fetch is presented, regardless of wind direction, by a near-rectangular form measuring 80 by 64 km at its greatest dimensions. This shallow "estuary" receives a massive inflow of 5040 m$^3$/sec (178,000 cfs) from the Detroit River and lesser discharges from the Maumee River, Raisin River, and numerous smaller tributaries (U.S. Army Corps of Engineers, 1960).

These physical characteristics, augmented by the low relief of the surrounding land and the continental nature of the climate, make thermal stratification in the Western basin seem unlikely. That it has occurred, perhaps more frequently than suspected, is suggested in a scattering of reports spanning the past 35 years. Brief periods of thermal stratification were detected in 1928–30 (Wright, 1955) and in 1938–42 (Chandler, 1940, 1942, 1944; Chandler and Weeks, 1945). These investigators found no evidence of chemical stratification concomitant with thermal stratification. Chandler (1944), in fact, stated that "Oxygen in western Lake Erie is never at any time seriously depleted and its vertical distribution is essentially uniform."

The first significant decrease in dissolved oxygen (DO) at a time of thermal stratification in western Lake Erie was found by Britt (1955a) in September 1953 after nearly a month of hot, calm weather. During 3 days at the end of this period the maximum DO at the bottom was only 1.2 ppm at his most frequently visited station near South Bass Island. The lowest DO that he recorded was 0.7 ppm at a station 2 miles west of this island. Although strong winds and cool weather restored complete circulation 4 days after chemical stratification was first found, the effect of the low DO on the mayfly (*Hexagenia*) population was catastrophic over a large area. Immediately after the period of stratification, Britt found large numbers of dead mayfly nymphs, but no live ones at locations where more than 1,000 per square meter were collected in 1952 (Wood, 1953). In other areas of the bottom between the Canadian shore and Catawba Island,

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[1] Manuscript received March 14, 1964.

the number of mayfly nymphs per square meter was only 44 where earlier in the year there had been 300 (mean densities). The mayfly population was almost completely restored by the following year (Britt, 1955b).

No thermal or chemical stratification was found during cruises of the U.S. Bureau of Commercial Fisheries M/V *Cisco* in the Western basin during the summer months of 1957 and 1958. The average number of mayfly nymphs per square meter, however, was only 40 in bottom samples taken in the same area studied by Britt (Beeton, 1961). This reduction in mayfly numbers to the same level as that found after the stratification in September 1953 suggests strongly that severe oxygen depletion in the bottom waters must have occurred at least once again after recovery of the mayfly population in 1954. It is evident now that the oxygen demand of the waters and/or bottom mud has become sufficiently great in the last decade to reduce the DO in the bottom waters rapidly whenever complete circulation is inhibited (Carr, 1962).

This report documents a second known occurrence of low DO accompanying stable (i.e., not diurnal) thermal stratification over a major portion of the Western basin of Lake Erie, compares the climatic conditions that led to thermal and chemical stratification in 1953 and 1963, and comments on the implications of these data.

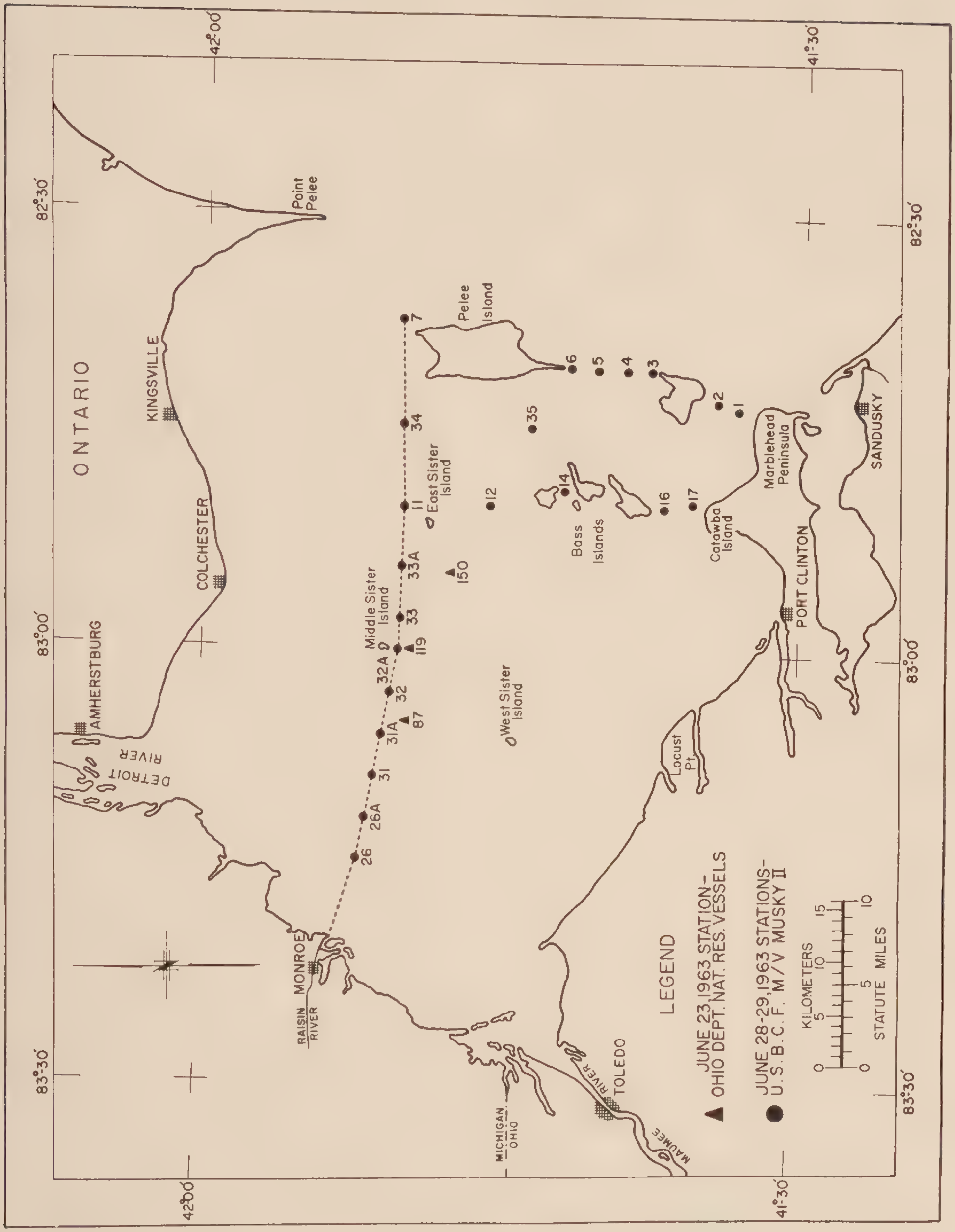
## THERMAL AND CHEMICAL STRATIFICATION IN JUNE 1963

A synoptic survey of the Western basin of Lake Erie was made on June 23, 1963, by the Geological Survey and Division of Wildlife, Ohio Department of Natural Resources. Limnological data were collected at 300 stations, including bathythermograph (BT) casts at 65 and DO measurements at 23 of these. Some degree of thermal stratification was shown by 38 of the BT recordings. Stratification evidently resulted from surface warming at most of these stations since all temperature changes were within 1.5 m of the surface. Definite signs of the beginning of more stable stratification were present at a few stations near the Sister Islands and Pelee Passage areas (fig. 1). The differences between surface and bottom temperatures at all stations were usually less than 3 C and changes within the metalimnion were less than 2 C.

The DO measurements during the synoptic survey were made in an area east of a north-south line from the middle of the Detroit River to Locust Point, Ohio, and west of a north-south line from Colchester, Ontario, to Catawba Island, Ohio. Dissolved oxygen in water samples taken 1.5 m below the surface ranged from 8.9 to 13.9 ppm at temperatures of 22.5 to 23.0 C; concentrations varied from 7.4 to 10.1 ppm at temperatures of 20.9 to 21.5 C in samples taken 0.6 m above the bottom. The DO on June 23, therefore, was near saturation at all depths and thermal stratification was just beginning.

The 4 days following the basin-wide synoptic of June 23 were almost cloudless, daytime temperatures were above 32 C, and winds were light and variable—ideal conditions for the formation of thermal stratification. Because of this somewhat unusual weather, data were collected on June 28–29 with the U.S. Bureau of Commercial Fisheries M/V *Musky II* to determine the effects of the hot, calm weather on the thermal structure of the waters of the Western basin. Sampling was limited to a series of stations along an east-west transect from the mouth of the Raisin River to the north tip of Pelee Island and to scattered stations along a north-south axis at the eastern end of the basin (fig. 1). Stations on the east-west transect were visited on June 28. Data were collected at the remaining stations on June 29.

Stable thermal stratification and low DO in the bottom water were found at nearly all stations (table 1). The metalimnion along the east-west transect had a relatively uniform thickness and was slightly deeper at the eastern than at the western end. It was bounded by a 24-C isotherm at the top and a 20-C isotherm


42°00'
41°30'
82°30'
83°00'
83°30'
ONTARIO
KINGSVILLE
COLCHESTER
AMHERSTBURG
DETROIT RIVER
Point Pelee
Pelee Island
East Sister Island
Middle Sister Island
West Sister Island
Bass Islands
Catawba Island
Marblehead Peninsula
SANDUSKY
PORT CLINTON
Locust Pt.
TOLEDO
MAUMEE RIVER
MICHIGAN
OHIO
RAISIN RIVER
MONROE
7
34
11
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119
87
150
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35
14
16
17
6
5
4
3
2
1
LEGEND
▲ JUNE 23, 1963 STATION–OHIO DEPT. NAT. RES. VESSELS
● JUNE 28-29, 1963 STATIONS–U.S. B.C.F. M/V MUSKY II
KILOMETERS 0 5 10 15
STATUTE MILES 0 5 10

FIGURE 1. Map of the Western basin of Lake Erie showing certain limnological stations visited in June 1963. The transect of stations used to construct the profile in figure 2 is indicated by a broken line.

at the bottom (fig. 2). The mean depths of the 24 C and 20 C isotherms were 3.0 m and 6.1 m. The change of 4 C within this 3-m depth identified the zone as a thermocline in the classical sense, i.e., a drop in temperature of at least 1 C with each meter of increasing depth. Temperature extremes along the transect were 24.2 C at the surface at station 26 and 17.8 C on the bottom at station 32 (figs. 1 and 2).

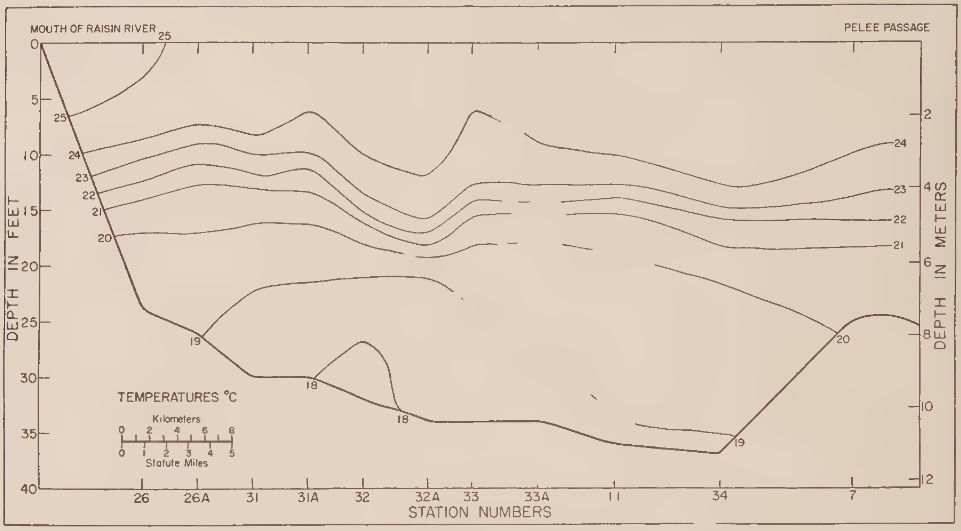

FIGURE 2. Profile of the Western basin of Lake Erie and isotherms found on June 28 along the east-west transect shown by the broken line in figure 1. Bottom conformation is based on depths shown on BT tracings. Isotherms indicated at intervals of 1 C were read from BT tracings.

TABLE 1

*Physical and chemical data collected in the Western basin of Lake Erie by the U.S.B.C.F. M/V* Musky II, *June 28–29, 1963**

| Station number | Date | Time (EST) | BT number | Surface temperature (C) | Station depth (m) | DO sampling depth (m) | DO (ppm) | Sample temperature (C) | Percent saturation of DO |
|---|---|---|---|---|---|---|---|---|---|
| 26 | 6–28 | 1105 | 1 | 25.4 | 7.3 | 6.1 | 2.6 | 20.0 | 30 |
| 26A | 6–28 | 1124 | 2 | 25.0 | 7.9 | 6.4 | 3.5 | 19.8 | 40 |
| 31 | 6–28 | 1145 | 3 | 25.0 | 9.1 | 7.6 | 3.7 | 19.1 | 41 |
| 32 | 6–28 | 1225 | 5 | 24.6 | 9.8 | 7.9 | 4.5 | 18.3 | 49 |
| 32A | 6–28 | 1251 | 6 | 25.0 | 10.4 | 7.6 | 4.1 | 19.0 | 46 |
| 33 | 6–28 | 1330 | 7 | 24.8 | 10.4 | 8.5 | 4.2 | 19.2 | 41 |
| 33A | 6–28 | 1351 | 8 | 25.0 | 10.4 | 0.3 | 10.7 | 24.9 | 136 |
| " | " | " | " | —— | " | 6.4 | 6.8 | 19.7 | 79 |
| " | " | " | " | —— | " | 8.2 | 3.8 | 19.2 | 43 |
| 34 | 6–28 | 1505 | 10 | 24.8 | 11.3 | 9.1 | 3.8 | 19.4 | 43 |
| 7 | 6–28 | 1550 | 11 | 24.7 | 7.6 | 4.6 | 6.7 | 20.7 | 79 |
| 16 | 6–29 | 0955 | 15 | 24.3 | 9.1 | 4.0 | 4.4 | 20.6 | 52 |
| " | " | " | " | —— | " | 7.6 | 3.3 | 20.2 | 38 |
| 14 | 6–29 | 1105 | 17 | 25.2 | 9.1 | 0.3 | 11.7 | 24.4 | 148 |
| " | " | " | " | —— | " | 7.3 | 3.3 | 20.1 | 38 |
| 12 | 6–29 | 1205 | 19 | 25.6 | 10.4 | 6.4 | 5.9 | 20.2 | 69 |
| " | " | " | " | —— | " | 7.6 | 4.5 | 20.0 | 53 |
| " | " | " | " | —— | " | 8.8 | 2.0 | 19.6 | 23 |
| 35 | 6–29 | 1320 | 20 | 25.6 | 10.4 | 7.0 | —— | 19.8 | —— |
| " | " | " | " | —— | " | 8.5 | 2.7 | 19.8 | 32 |
| " | " | " | " | —— | " | 9.1 | 2.6 | 19.1 | 30 |
| 5 | 6–29 | 1410 | 22 | 25.1 | 9.4 | 8.5 | 4.2 | 20.3 | 49 |
| 4 | 6–29 | 1418 | 23 | 24.5 | 13.4 | 12.8 | 2.7 | 19.2 | 31 |
| 3 | 6–29 | 1430 | 24 | 24.2 | 13.4 | 12.5 | 3.8 | 20.0 | 43 |
| 2 | 6–29 | 1550 | 26 | 24.2 | 7.9 | 7.0 | 5.3 | 20.0 | 61 |
| 1 | 6–29 | 1555 | 27 | 23.1 | 9.4 | 8.8 | 3.8 | 19.2 | 43 |

*Does not include 4 stations at which only BT recordings were made. Recordings for stations 11 and 31A are incorporated in figure 2; those for stations 17 and 6 are illustrated in figures 4 and 5, respectively.

The striking change in vertical temperature profiles that took place between June 23 and 28 is well illustrated by BT recordings at 4 stations within a small area south and west of Middle Sister Island (fig. 3). In this locality the upper waters warmed about 3 C and the bottom waters cooled about 2 C in the 5-day interval. The reason for the increase in the upper waters is clear, but the cause of the decrease of temperature in the bottom waters is less easily explained. As a general rule, the main stream of the Detroit River is much cooler than the water of the Western basin during the summer. On June 24, however, water temperatures at the mouth of the river were above 19 C or approximately 1.5 C warmer than the coldest bottom water in the Western basin on June 28. Either heat loss to the bottom sediments or the intrusion of colder water from the Central basin by internal waves are the most probable causes of this difference.

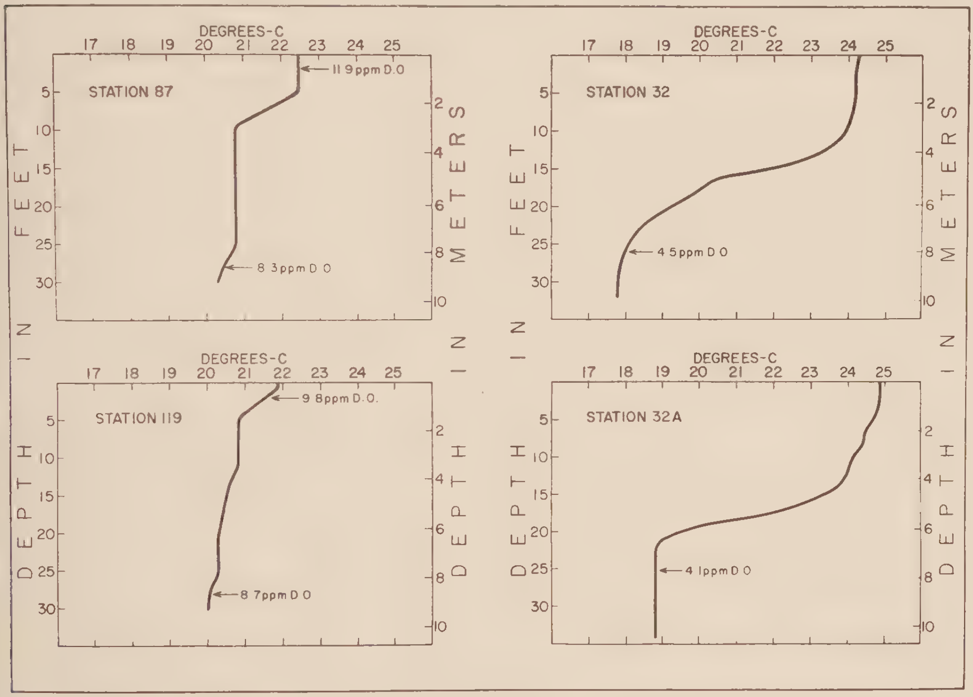

FIGURE 3. BT recordings at stations 87 and 119 on June 23, 1963, and at nearby stations 32 and 32A on June 28, 1963. Oxygen measurements are indicated at depths where samples were taken. See figure 1 for location of stations.

The DO in the bottom waters was below 50 per cent of saturation at all stations along the east-west transect except station 7 northeast of Pelee Island (table 1). The lowest DO was 2.6 ppm (30 per cent of saturation) at station 26, near the outer buoy of the Raisin River shipping channel. Since a Nansen bottle was used for all water samples collected on June 28, no DO measurements could be made deeper than 1.4 m above the bottom. Dissolved oxygen at the mud-water interface was undoubtedly lower than the lowest values we report for the "bottom waters." The substantial decrease in oxygen content that accompanied a small change in depth and temperature is illustrated by conditions at station 33A (fig. 4). The difference in depth between two sampling points below the metalimnion at this station was about 1.8 m and the difference in temperature was only 0.5 C; yet within this interval the DO decreased by 3 ppm. If a similar rate of change occurred between the deepest sample and the bottom, the expected DO at the mud-water interface would be about 1 ppm. The inability of conventional water sampling devices to take samples in a narrow stratum just above the bottom may explain why previous studies have not reported more incidents of low DO in the bottom waters in Lake Erie (Carr, 1962).

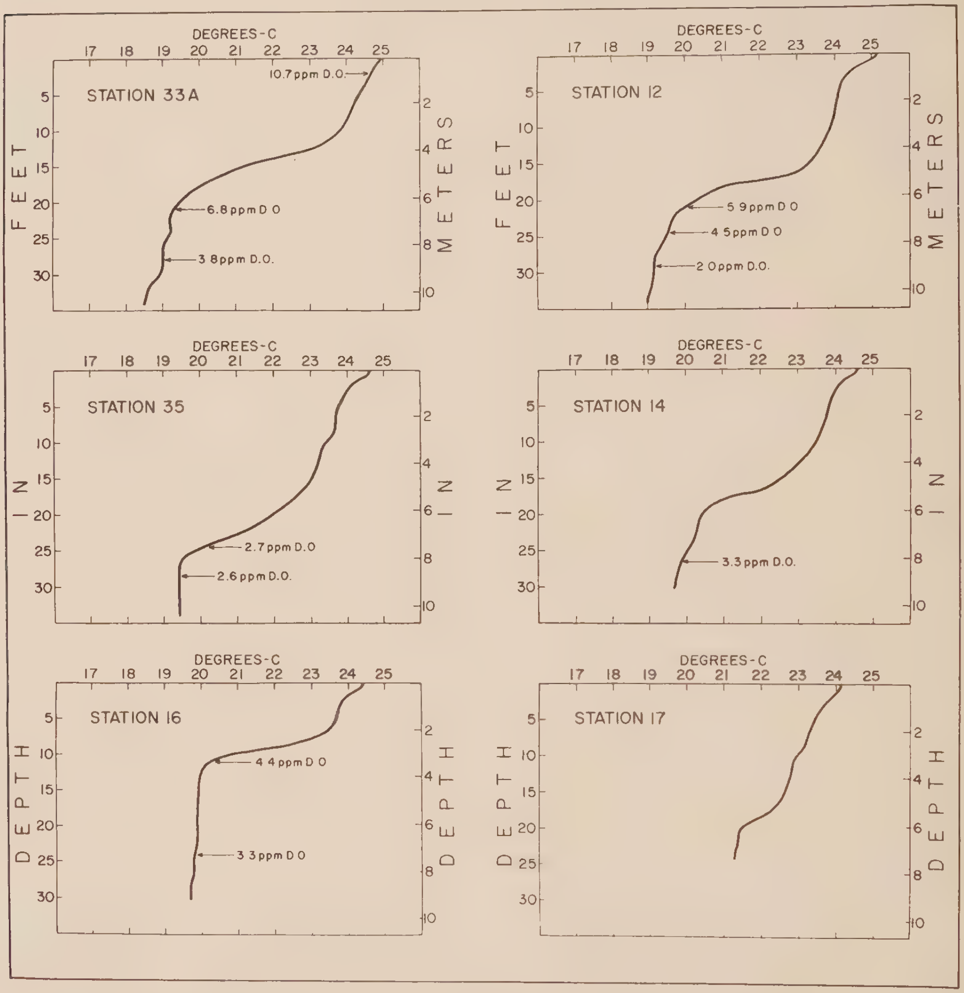

FIGURE 4. BT recordings at stations 12, 14, 16, 17, 33A, and 35 on June 28–29, 1963. Oxygen measurements are indicated at depths where samples were taken. See figure 1 for location of stations.

Most of the stations visited, other than those on the east-west transect, were located in passages between islands and are not necessarily typical of conditions in the more open waters. Diversity of thermal structure and DO content apparently were as great among stations in the same passage as in different passages (figs. 4 and 5). Differences were particularly pronounced between stations 16 and 17 and, to a lesser extent, between stations 1 and 2, all of which are in the South Passage. Conditions were similar at stations 3, 4, 5, and 6 between Kelleys and Pelee Islands.

The area with the greatest depletion of DO on June 29 lay north and east of the Bass Islands and due west of Pelee Island (stations 12 and 35, fig. 1). The lowest level of dissolved oxygen found during the 2 days was 2.0 ppm at station 12. At the point nearest station 12, visited on June 23 (station 150, fig. 1), the water was homothermous with a DO content of 8.9 ppm at a depth 0.6 m above the bottom. In the 6 days between samplings, the average rate of oxygen consumption in the general area represented by the two stations was over 1 ppm per day. A similar rate of reduction was found in all areas in which comparisons could be made between conditions on June 23 and June 28–29. At this high rate of oxygen use, only a few days of stable conditions would be required before the oxygen deficiency would be lethal to sensitive bottom fauna.

Records of the U.S. Weather Bureau at Sandusky, Ohio, show that the hot,

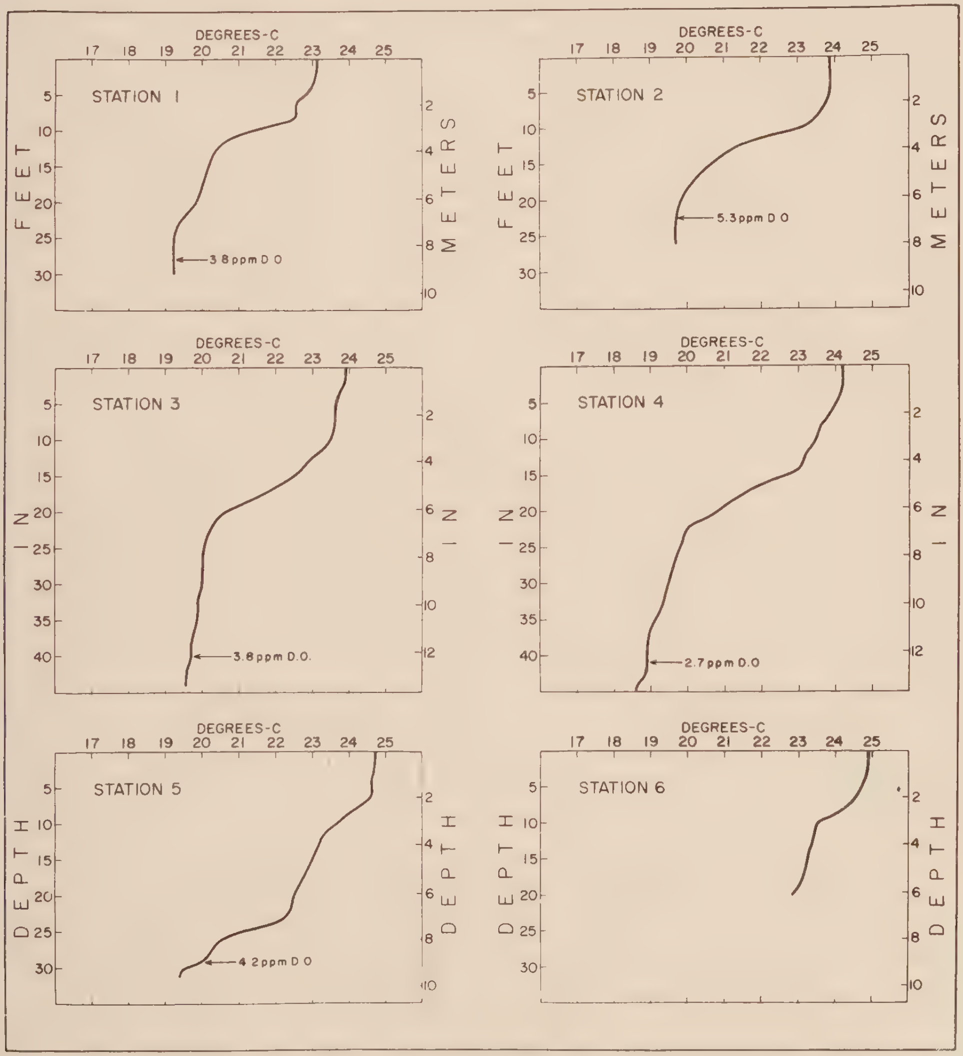

FIGURE 5. BT recordings at stations 1–6 on June 29, 1963. Oxygen measurements are indicated at depths where samples were taken. See figure 1 for location of stations.

calm weather that produced the stratification found on June 28–29 lasted until July 2. Oxygen depletion in the bottom waters obviously could not have continued at a rate of 1 ppm per day. It is very likely, however, that the DO in the bottom waters was less on July 1 than on June 29 when the last measurements were made. Water samples taken on July 9 during a subsequent cruise of the U.S. Bureau of Commercial Fisheries M/V *Kaho* revealed no thermal stratification or low DO in the entire island area of the Western basin.

## CAUSES AND EFFECTS OF THERMAL STRATIFICATION IN WESTERN LAKE ERIE

We have given previously several reasons why western Lake Erie would not be expected to stratify thermally. Stratification does occur, however, when certain extreme climatic conditions prevail for a sufficient period to overcome the physical features of the basin. Our observations on June 23 and June 28–29 and records of the U.S. Weather Bureau during this period permit us to delineate the climatic conditions that should induce thermal stratification in a 5-day interval in any month from June to September. These conditions are: a daily average wind speed of less than 6 knots; a highest wind speed of less than 13 knots; and an average daily temperature of more than 18 C.

Weather records for Sandusky, Ohio, show that these or greater extremes of hot, calm weather occurred for 5 or more days on 33 occasions in the years 1953–1963. At least one such period occurred during each of the 11 years. The length of these periods varied from 5 to 28 days (average 7.5). The data strongly suggest that stable thermal stratification occurs in western Lake Erie more regularly and frequently than was heretofore suspected.

Not all periods of possible thermal stratification were necessarily accompanied by low DO in the bottom waters. In 1953, 28 days of hot, calm weather were required to reduce the oxygen in the bottom waters of the Western basin to critical levels, whereas only 5 days were required in 1963. We attribute this change to increased oxygen demand of the bottom muds in recent years.

Thermal stratification in western Lake Erie, unaccompanied by oxygen depletion, is largely of academic interest. On the other hand, oxygen depletion during these periods of thermal stratification has profound practical significance. Low DO in the bottom waters not only kills important benthic organisms but occasionally leads to significant fish mortalities. The volume of urban and agricultural drainage discharged into western Lake Erie has increased steadily for decades. Apparently some critical level was passed between World War II and 1953, which has brought about serious oxygen depletion during extended periods of thermal stratification. Since the rate of "enrichment" continues to increase, we can expect low DO in the bottom waters to occur with increasing frequency as less pronounced incidents of thermal stratification become capable of producing the same degree of severe depletion. If we again experience a 28-day period of calm, hot weather similar to that of 1953, it is likely that mortalities of fishes as well as other aquatic organisms in the Western basin will be without precedent.

## ACKNOWLEDGMENTS

We wish to thank Robert P. Hartley, Geological Survey Division, Ohio Department of Natural Resources, who provided data collected during the synoptic survey of June 23, 1963, and the many staff members of the Ohio Wildlife and Geological Survey Divisions and the U.S. Bureau of Commercial Fisheries who aided in the collection of data.

## LITERATURE CITED

**Beeton, A. M.** 1961. Environmental changes in Lake Erie. Trans. Am. Fish. Soc. 90: 153–159.

**Britt, N. W.** 1955a. Stratification in western Lake Erie in summer of 1953; effects on the *Hexagenia* (Ephemeroptera) population. Ecology 36: 239–244.

———. 1955b. *Hexagenia* (Ephemeroptera) population recovery in western Lake Erie following the 1953 catastrophe. Ecology 36: 520–522.

**Carr, J. F.** 1962. Dissolved oxygen in Lake Erie, past and present. The Univ. of Mich., Inst. Sci. and Tech., Great Lakes Res. Div., Publ. No. 9: 1–14.

**Chandler, D. C.** 1940. Limnological studies of western Lake Erie. I. Plankton and certain physical-chemical data of the Bass Island Region, from September, 1938, to November, 1939. Ohio J. Sci. 40: 291–336.

———. 1942. Limnological studies of western Lake Erie. III. Phytoplankton and physical-chemical data from November, 1939, to November, 1940. Ohio J. Sci. 42: 24–44.

———. 1944. Limnological studies of western Lake Erie. IV. Relationship of limnological and climatic factors to the phytoplakton of 1941. Trans. Am. Micro. Soc. 43: 203–236.

———, and **O. B. Weeks.** 1945. Limnological studies of western Lake Erie. V. Relation of limnological and meterological conditions to the production of phytoplankton in 1942. Ecol. Monogr. 15: 435–456.

**U.S. Army, Corps of Engineers.** 1960. Great Lakes pilot. U.S. Lake Survey, Detroit, Mich. 451 p.

**Wood, K. G.** 1953. Distribution and ecology of certain bottom-living invertebrates of the western basin of Lake Erie. Ph.D. Thesis. The Ohio State University. (Unpublished).

**Wright, S.** 1955. Limnological survey of western Lake Erie. U.S. Dept. of the Int., Fish and Wildl. Serv., Spec. Sci. Rept.: Fisheries No. 139. 341 p.

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# CHANGES IN THE BOTTOM FAUNA OF WESTERN LAKE ERIE FROM 1930 TO 1961

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ABSTRACT

Samples were collected at 40 stations in western Lake Erie in 1961 to determine the species composition, distribution, and abundance of macrobenthonic organisms and to document changes since 1930, when a similar survey was made. The fauna in 1961 was composed principally of Oligochaeta, Tendipedidae (7 genera), Sphaeriidae (15 species), and Gastropoda (at least 8 species). Stations with a high density of Oligochaeta were near the principal sources of pollution (Maumee, Raisin, and Detroit rivers). Stations with fewer Oligochaeta and a more diverse fauna were farthest from the river mouths. The population density of the burrowing mayfly, *Hexagenia* spp., was reduced from an average of 139/m$^2$ in 1930 to less than 1/m$^2$ in 1961. Organisms more abundant near the sources of pollution than in other areas were, in addition to Oligochaeta: the midge, *Procladius*; the fingernail clam, *Sphaerium transversum*; and the snail, *Valvata sincera* (sens. lat.). Organisms sensitive to pollution, such as amphipods, mayfly nymphs, caddisfly larvae, and naiad clams, were scarce and usually at the more lakeward stations. The most important changes in fauna during the 31-year period were: ninefold increase in Oligochaeta; fourfold increase in Tendipedidae; twofold increase in Sphaeriidae; sixfold increase in Gastropoda; and a reduction of *Hexagenia* to less than 1% of former abundance. The area of pollution (as judged from the abundance of Oligochaeta) increased from 263 km$^2$ in 1930 to 1,020 km$^2$ in 1961.

## INTRODUCTION

Environmental changes in Lake Erie have been the subject of several recent papers. Beeton's (1961) comparison of data collected over the past 60 years demonstrated major changes in the species composition and abundance of fish and bottom fauna. He also reported that concentrations of major ions have increased as much as 10 ppm; mean annual water temperatures have been approximately 1.1C warmer in recent years than in 1918–1928; and oxygen in the bottom waters now becomes depleted in certain months over a large area. Carr (1962) described the recent expansion of areas of oxygen depletion in the central basin. Beeton (1965) classified Lake Erie as eutrophic in the classical sense and showed how the lake has shifted into this category in the past 35 years. The temporary effects of a short period of thermal stratification and low oxygen in the western basin were reported by Britt (1955*a*, *b*). Carr, Applegate, and Keller (1965) gave evidence of the increasing frequency of oxygen depletion during thermal stratification in the western basin and discussed factors causing these conditions. Davis (1964) supported the idea of rapid recent eutrophication of Lake Erie on the basis of a progressive increase in the average quantity of phytoplankton between 1919 and 1964. Increased use of chemical fertilizers in the Maumee River watershed was given as a cause of changes in western Lake Erie by Verduin (1964). Bradshaw (1964) showed substantial quantitative and qualitative changes in the crustacean zooplankton of the island area of the western basin between 1938 and 1959.

Studies of the bottom fauna have been concentrated in the western basin, particularly in the island area, for which the composition of the macrofauna prior to the mid-1950's is well known (Wood 1963). Information is scanty, however, on the central and eastern basins and the extreme western end of Lake Erie. The only detailed work in the vicinity of the Detroit River was in 1930 (Wright 1955). Brown (1953) reported on a limited study of the bottom fauna in the lower Maumee River and Maumee Bay. Data on changes in bottom fauna were given by Brown (1953), Britt (1955*a*, *b*), and Beeton (1961).

The objective of the 1928–1930 survey of

Table 1. *Numbers and locations of sampling stations in western Lake Erie, 1930 and 1961*

| Year and station number | | Location | |
|---|---|---|---|
| 1930 | 1961 | N latitude | W longitude |
| | Maumee Bay Area | | |
| 251 | 1M | 41°42′50″ | 83°25′30″ |
| 252 | 2M | 41°43′40″ | 83°23′20″ |
| 253 | 3M | 41°44′30″ | 83°21′20″ |
| 254 | 4M | 41°45′20″ | 83°19′10″ |
| 256 | 5M | 41°46′20″ | 83°17′10″ |
| 107 | 6M | 41°42′50″ | 83°16′10″ |
| 109 | 7M | 41°44′00″ | 83°17′50″ |
| 114 | 8M | 41°47′20″ | 83°21′20″ |
| | Raisin River Area | | |
| 116 | 1R | 41°49′00″ | 83°23′40″ |
| 116D | 2R | 41°50′40″ | 83°21′10″ |
| 210 | 3R | 41°53′10″ | 83°19′50″ |
| 117 | 4R | 41°52′50″ | 83°17′50″ |
| 264 | 5R | 41°52′20″ | 83°15′50″ |
| — | 6R | 41°54′10″ | 83°18′00″ |
| | Detroit River Area | | |
| 119 | 1D | 41°54′40″ | 83°15′10″ |
| 121 | 2D | 41°55′30″ | 83°15′10″ |
| 123 | 3D | 41°56′20″ | 83°12′10″ |
| 130 | 4D | 41°54′50″ | 83°08′10″ |
| 240 | 5D | 41°57′30″ | 83°11′40″ |
| 128 | 6D | 41°56′30″ | 83°08′40″ |
| 231 | 7D | 41°56′20″ | 83°05′20″ |
| 232 | 8D | 41°57′20″ | 83°07′10″ |
| 126 | 9D | 41°58′10″ | 83°09′10″ |
| — | 10D | 41°59′20″ | 83°09′50″ |
| — | 11D | 41°59′20″ | 83°07′30″ |
| 226–227 | 12D | 41°58′50″ | 83°05′30″ |
| 222 | 13D | 42°00′30″ | 83°09′10″ |
| — | 14D | 42°00′30″ | 83°06′00″ |
| 221-B | 15D | 42°02′00″ | 83°09′10″ |
| — | 16D | 42°01′30″ | 83°04′10″ |
| | Open-lake Area | | |
| 236 | 1L | 41°43′10″ | 83°12′00″ |
| 258 | 2L | 41°47′50″ | 83°13′50″ |
| 259 | 3L | 41°49′00″ | 83°10′50″ |
| 263 | 4L | 41°51′50″ | 83°13′10″ |
| 262 | 5L | 41°51′30″ | 83°11′00″ |
| 134 | 6L | 41°50′50″ | 83°07′00″ |
| — | 7L | 41°49′00″ | 83°00′00″ |
| 132 | 8L | 41°53′00″ | 83°07′50″ |
| 229–230 | 9L | 41°55′00″ | 83°02′20″ |
| — | 10L | 41°53′40″ | 82°59′10″ |

the western basin was to determine the effects of pollution on the decline of commercially important fishes during the late 1920's (Wright 1955). One of the major criteria of pollution was the composition of the bottom fauna. Wright compared conditions in the lake far from sources of pollution with those near suspected sources and established a series of sampling stations along lines extending from areas of suspected pollution to areas believed to be free from pollution. In the present study, 33 of the stations established in 1930 were resampled and seven new stations were established (Table 1) to determine the current status of the bottom fauna of the extreme western end of the lake and to document changes since 1930. Wright's study included three years of fieldwork, but only the quantitative data for 1930 were adequate for study of changes.

Wright established an empirical standard for classifying degrees of pollution, based on the abundance of oligochaetes (primarily Tubificidae): 1) heavy pollution, more than 5,000 oligochaetes/m$^2$; 2) moderate pollution, 1,000 to 5,000; and 3) light pollution, 100 to 999. Although this system has serious shortcomings, it does provide an excellent basis for comparing changes. His classification is used here for comparison of the zones of pollution as they existed in 1930 and in 1961.

This paper is divided into two major sections. The first describes the distribution and abundance of the major groups of organisms in the extreme western part of Lake Erie in 1961 (the polychaete, *Manayunkia speciosa* is not included—for a discussion of this species *see* Hiltunen 1965); the second section reviews changes in the bottom fauna between 1930 and 1961.

The authors acknowledge the assistance of LaVerne L. Curry (Tendipedidae), H. B. Herrington (Sphaeriidae), and Henry van der Schalie (Unionidae) in the identification of organisms. The figures were prepared by William Cristanelli.

## DESCRIPTION OF WESTERN LAKE ERIE

The boundaries of the area studied include the entire Michigan shoreline of Lake Erie to the west, the mouth of the Detroit River to the north, Maumee Bay to the south, and West Sister Island and Middle Sister Island to the east (Fig. 1). This part of Lake Erie receives more than 90% of the lake's total inflow. The Detroit River has a mean flow of 5,032 m³/sec and accounts for approximately 97% of the inflow into western Lake Erie. The mean annual discharge of the Maumee River is about 142 m³/sec, although the flow may exceed 1,132 m³/sec during short periods of rapid runoff. The discharge during these periods increases considerably the turbidity and phosphorus content of the water in Maumee Bay and along the Ohio shore as far east as Sandusky, Ohio (72 km east of Toledo, Ohio). Among lesser tributaries, the Raisin River, with a mean discharge of 20 m³/sec, enters the lake along the central western boundary. The basins of streams that flow into western Lake Erie include urban areas and extensive industrial and agricultural developments.

The maximum water depth in western Lake Erie is approximately 11 m. Ship channels dredged to a depth of 6.4 to 7.9 m extend 27 km northeastward from the mouth of the Maumee River, 5 km southeastward from the mouth of the Raisin River, and 10 km south from the mouth of the Detroit River.

The region investigated was divided into four geographic areas based on the estimated influence of the three major rivers (Fig. 1). This division permits comparisons of the bottom fauna at the stations influenced by rivers with those in the open lake and of the river areas with each other.

## METHODS

Samples were taken with a Petersen dredge between 31 May and 16 June 1961, from the *MV Musky II*. The maximum and minimum sampling depths were 10.4 and 2.4 m. Stations were about evenly divided between depths of 2 to 6 m and 7 to 11 m. The sampling area of the dredge was 743 cm². Three samples were taken at each station and washed by suspending them over the side of the vessel in cloth bags of No. 36 grit cloth (approx 0.5 mm diam). The bottom material was transferred from the bags to a wire screen box (No. 30 mesh, 0.6 mm diam) and gently rewashed with a stream of water under low pressure. The samples were preserved in glass jars in 10% formalin. The organisms were counted individually under a low-power (15×) dissecting microscope. The three samples from each station were examined separately, but records of numbers per m² in the text and tables were computed from the combined samples.

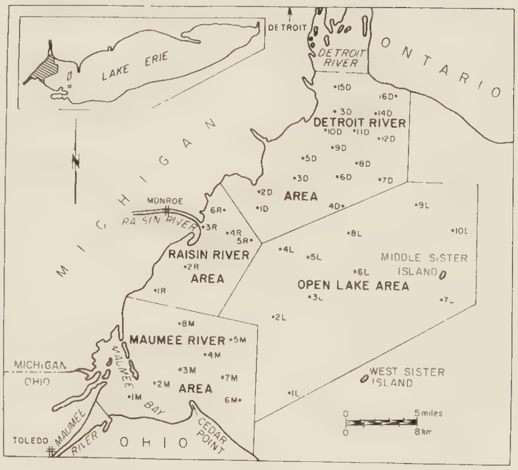
DETROIT
DETROIT RIVER
ONTARIO
LAKE ERIE
MICHIGAN
MONROE
RAISIN RIVER
•15D
•16D•
•13D
•14D
DETROIT RIVER
•10D
•11D
•12D
•9D
•5D
•8D
•3D
•6D
•7D
•2D
AREA
•1D
4D•
•9L
6R•
•3R
•4R
5R•
•8L
•10L
•4L
•5L
MIDDLE SISTER ISLAND
RAISIN RIVER
•2R
AREA
•6L
OPEN LAKE AREA
•1R
•3L
•7L
•2L
•8M
MAUMEE RIVER •5M
•4M
MICHIGAN
OHIO
MAUMEE BAY
•3M
•7M
•2M
AREA
WEST SISTER ISLAND
•1M
6M•
•1L
0
5 miles
0
8 km
TOLEDO
MAUMEE RIVER
OHIO
CEDAR POINT

Fig. 1. Location of study areas and sampling stations in western Lake Erie.

Samples were collected at 40 stations, of which 33 were considered to be near enough to the 1930 stations (within 400 m) for direct comparison; these are listed with the corresponding 1930 station numbers in Table 1. The isopleths in Figs. 2 through 8, 10, and 13 were drawn assuming constant rates of change in numbers of organisms between stations.

## ABUNDANCE AND DISTRIBUTION OF BOTTOM FAUNA IN 1961

The diversity of macroinvertebrate fauna was relatively great. In addition to Oligochaeta and Hirudinea, which were not classified as to genus or species, 32 genera and at least 48 species were represented in the samples; the number of genera at individual stations ranged from five to 17 and the number of identified species from five to 27; fewer than eight genera were found at 12 stations, and 15 or more were collected at six.

The three principal groups of organisms, both in terms of numbers and distribution,

TABLE 2. *Depth of water, bottom type, and density (no./m$^2$) of bottom organisms at 40 stations in western Lake Erie, 1961* (Bottom types: C = clay, G = gravel, M = mud, S = sand, Sh = shells)*

| | | | Dominant taxonomic groups | | | | Other taxonomic groups | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Area and station | Depth (m) | Bottom type | Oligochaeta | Diptera (Tendipedidae) | Pelecypoda (Sphaeriidae) | Gastropoda | Hirudinea | Amphipoda (*Gammarus*) | Ephemeroptera (*Hexagenia*) | Trichoptera | Diptera (*Chaoborus*) | Pelecypoda (Unionidae) | Total organisms |
| Maumee River | | | | | | | | | | | | | |
| 1M | 2.4 | M | 9,004 | 378 | 0 | 0 | 0 | 0 | 0 | 0 | 54 | 0 | 9,436 |
| 2M | 2.4 | MS | 7,168 | 797 | 108 | 9 | 23 | 4 | 0 | 0 | 14 | 4 | 8,127 |
| 3M | 3.4 | M | 10,300 | 675 | 81 | 9 | 27 | 14 | 0 | 0 | 23 | 0 | 11,129 |
| 4M | 5.2 | M | 2,781 | 324 | 45 | 9 | 18 | 4 | 14 | 0 | 0 | 0 | 3,195 |
| 5M | 6.4 | M | 1,714 | 216 | 135 | 4 | 18 | 0 | 0 | 4 | 0 | 9 | 2,100 |
| 6M | 5.5 | M | 1,984 | 351 | 14 | 0 | 4 | 0 | 0 | 0 | 0 | 0 | 2,353 |
| 7M | 5.5 | M | 4,306 | 256 | 4 | 0 | 23 | 0 | 0 | 0 | 0 | 4 | 4,593 |
| 8M | 5.5 | M | 3,010 | 68 | 14 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 3,092 |
| Raisin River | | | | | | | | | | | | | |
| 1R | 3.7 | MS | 4,185 | 634 | 14 | 4 | 4 | 0 | 0 | 4 | 0 | 0 | 4,845 |
| 2R | 4.0 | SM | 9,328 | 297 | 0 | 23 | 0 | 23 | 4 | 0 | 0 | 0 | 9,675 |
| 3R | 2.4 | M | 13,311 | 310 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 13,621 |
| 4R | 5.2 | SM | 10,854 | 162 | 716 | 1,040 | 27 | 23 | 0 | 4 | 0 | 9 | 12,835 |
| 5R | 6.4 | MSSh | 1,026 | 446 | 1,242 | 999 | 31 | 9 | 0 | 0 | 0 | 27 | 3,780 |
| 6R | 4.9 | SM | 4,144 | 729 | 50 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 4,923 |
| Detroit River | | | | | | | | | | | | | |
| 1D | 6.7 | M | 594 | 189 | 126 | 54 | 4 | 0 | 0 | 0 | 0 | 0 | 967 |
| 2D | 5.5 | M | 4,347 | 648 | 36 | 50 | 4 | 0 | 0 | 0 | 0 | 4 | 5,089 |
| 3D | 7.3 | M | 1,066 | 50 | 338 | 126 | 14 | 0 | 0 | 0 | 0 | 0 | 1,594 |
| 4D | 8.5 | M | 1,256 | 540 | 554 | 131 | 27 | 0 | 0 | 0 | 0 | 9 | 2,517 |
| 5D | 5.5 | S | 5,008 | 4 | 99 | 4 | 4 | 0 | 0 | 0 | 0 | 4 | 5,123 |
| 6D | 7.3 | M | 1,593 | 50 | 418 | 45 | 0 | 0 | 0 | 0 | 0 | 0 | 2,106 |
| 7D | 7.9 | M | 2,781 | 230 | 310 | 40 | 9 | 4 | 0 | 0 | 0 | 9 | 3,383 |
| 8D | 7.0 | M | 13,014 | 270 | 324 | 40 | 14 | 0 | 0 | 0 | 0 | 0 | 13,662 |
| 9D | 5.5 | M | 20,952 | 94 | 1,620 | 40 | 189 | 0 | 0 | 0 | 0 | 0 | 22,895 |
| 10D | 4.6 | M | 29,308 | 99 | 945 | 81 | 14 | 0 | 0 | 0 | 0 | 0 | 30,447 |
| 11D | 6.1 | MSCG | 5,508 | 1,323 | 1,836 | 142 | 27 | 0 | 7 | 14 | 0 | 7 | 8,864 |
| 12D | 7.3 | SM | 3,564 | 810 | 1,688 | 446 | 54 | 0 | 9 | 0 | 0 | 0 | 6,571 |
| 13D | 3.7 | M | 39,164 | 18 | 675 | 189 | 14 | 0 | 0 | 0 | 0 | 0 | 40,060 |
| 14D | 5.8 | MSG | 1,796 | 729 | 648 | 230 | 9 | 0 | 0 | 9 | 0 | 4 | 3,425 |
| 15D | 4.6 | M | 14,688 | 90 | 2,862 | 50 | 9 | 0 | 0 | 0 | 0 | 0 | 17,699 |
| 16D | 3.4 | S | 500 | 40 | 189 | 0 | 0 | 23 | 0 | 4 | 0 | 0 | 756 |
| Open lake | | | | | | | | | | | | | |
| 1L | 7.6 | SGM | 1,418 | 662 | 675 | 189 | 81 | 95 | 4 | 28 | 0 | 14 | 3,166 |
| 2L | 7.6 | M | 284 | 72 | 31 | 4 | 18 | 0 | 0 | 0 | 0 | 0 | 409 |
| 3L | 7.9 | SMSh | 1,876 | 176 | 2,524 | 1,161 | 68 | 104 | 0 | 14 | 0 | 31 | 5,954 |
| 4L | 7.3 | MSSh | 3,105 | 540 | 2,120 | 540 | 176 | 54 | 4 | 45 | 0 | 9 | 6,593 |
| 5L | 8.2 | MSSh | 405 | 216 | 243 | 90 | 9 | 9 | 0 | 4 | 0 | 4 | 980 |
| 6L | 9.1 | MSh | 648 | 81 | 621 | 148 | 122 | 67 | 4 | 14 | 0 | 23 | 1,728 |
| 7L | 10.4 | M | 729 | 216 | 472 | 135 | 63 | 14 | 0 | 4 | 0 | 9 | 1,642 |
| 8L | 9.1 | SM | 972 | 675 | 972 | 126 | 50 | 23 | 0 | 9 | 0 | 31 | 2,858 |
| 9L | 9.8 | MS | 621 | 432 | 148 | 54 | 31 | 0 | 0 | 0 | 0 | 4 | 1,290 |
| 10L | 10.1 | MSh | 1,269 | 297 | 1,107 | 162 | 45 | 9 | 0 | 0 | 0 | 4 | 2,893 |

* Other organisms found but not listed were: Plecoptera—4 at 2R; Coleoptera—4 at 3R; and Hydracarina—4 at 9D.

were oligochaetes (contributed 84% of the total organisms, and were collected at all stations), fingernail clams (8% of the total number and at 92% of the stations), and midge larvae (5% of the total number and at all stations). A fourth group, the gastropods, contributed 2% of the total organisms and were collected at 82% of the stations. These four groups are discussed in the following section; the groups represented less frequently—Hirudinea, Amphipoda, Ephemeroptera, Trichoptera, Diptera (*Chaoborus*), and Unionidae—are treated in a later section.

The total number of organisms ranged from 409/m² at Station 2L to 40,060/m² at Station 13D (Table 2). The five stations with the largest number of organisms/m² (13,662 to 40,060) were in the Detroit River area. If oligochaetes are excluded, the number of organisms ranged from 82/m² at Station 8M to 4,078/m² at Station 3L.

### *Major taxonomic groups*

*Oligochaeta.* Although more than one family of the order Oligochaeta was represented in the bottom samples, at least 99% were Tubificidae. A great abundance of these worms has long been regarded as indicative of organic enrichment. According to Hynes (1960, p. 112), "Where only very little oxygen remains in the water, or the river bed is completely covered over with organic solids or sewage fungus, the main inhabitants are always the so-called sludge worms of the family Tubificidae."

The numerical dominance of the bottom fauna by oligochaetes is apparent from the large numbers collected at almost every station (Table 2). They were more numerous than any other taxonomic group at all but three stations; at only 10 stations did they contribute less than 50% of the total organisms and at 21 they made up more than 80%. The number of worms ranged from 284 to 39,164/m².

Oligochaetes were most abundant near the mouths of the Detroit, Raisin, and Maumee rivers, and least numerous at stations farthest from the river mouths. Since abundance of oligochaetes is related directly to the amount of organic enrichment, these streams clearly are the major sources of pollution in western Lake Erie. Although stations near each river mouth had more than 10,000 worms/m², the number exceeded 15,000/m² only in the Detroit River area. This high count does not in itself justify the designation of the mouth of the Detroit River as the most heavily polluted region, because other less tolerant organisms were more abundant here than at certain stations with smaller worm counts.

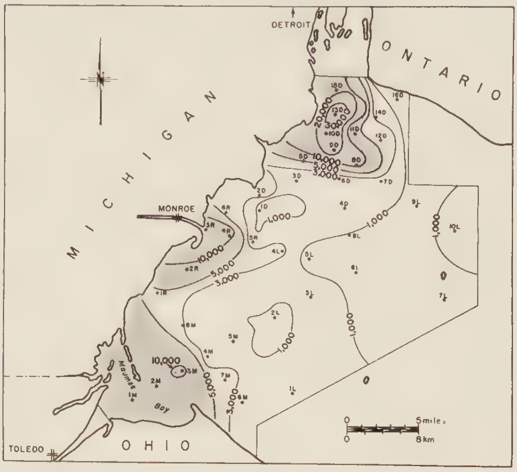

FIG. 2. Distribution of Oligochaeta (no./m²) in western Lake Erie, 1961. The density of Oligochaeta in shaded areas was 5,000/m² or more.

The number of worms at each station, although small in comparison to the enormous values (up to 300,000/m²) that have been recorded in some environments (Richardson, *cited in* Hynes 1960), exceeds the figures listed for some polluted Michigan lakes. Surber's (1957) summary of the bottom fauna of six polluted inland Michigan lakes and polluted areas of Green Bay (Lake Michigan) and Saginaw Bay (Lake Huron) gave the maximum density of oligochaetes as 22,510/m² (in a polluted area of Muskegon Lake). The average number from all the lakes was slightly less than 5,000/m², the figure used by Wright (1955) as a dividing point between moderate and heavy pollution. By Wright's standard, the water at 13 stations in the present study was heavily polluted.

The 5,000/m² isopleth in Fig. 2 indicates approximately the areas of heavy organic enrichment from the inflow from the three major rivers.

*Tendipedidae.* Larvae of the dipteran family Tendipedidae were collected at all stations, usually in fairly large numbers (average, 355/m²). The heaviest concentra-

TABLE 3. *Density (no./m²) of different genera of Tendipedidae in western Lake Erie, 1961**

| Area and station | Genus | | | |
|---|---|---|---|---|
| | *Coelotanypus* | *Cryptochironomus* | *Procladius* | *Tendipes* |
| Maumee River | | | | |
| 1M | 45 | 4 | 328 | 0 |
| 2M | 31 | 9 | 756 | 0 |
| 3M | 27 | 31 | 621 | 0 |
| 4M | 162 | 0 | 162 | 0 |
| 5M | 108 | 0 | 85 | 23 |
| 6M | 176 | 0 | 166 | 4 |
| 7M | 77 | 0 | 148 | 23 |
| 8M | 23 | 4 | 31 | 9 |
| Average | 81 | 6 | 287 | 7 |
| Raisin River | | | | |
| 1R | 108 | 117 | 126 | 50 |
| 2R | 27 | 63 | 189 | 23 |
| 3R | 4 | 4 | 297 | 0 |
| 4R | 45 | 9 | 104 | 0 |
| 5R | 144 | 31 | 256 | 9 |
| 6R | 58 | 0 | 675 | 0 |
| Average | 64 | 37 | 274 | 14 |
| Detroit River† | | | | |
| 1D | 80 | 4 | 108 | 0 |
| 2D | 0 | 0 | 648 | 0 |
| 3D | 4 | 0 | 45 | 0 |
| 4D | 185 | 0 | 351 | 0 |
| 5D | 0 | 0 | 4 | 0 |
| 6D | 14 | 0 | 36 | 0 |
| 7D | 90 | 0 | 148 | 0 |
| 8D | 4 | 0 | 270 | 0 |
| 9D | 0 | 0 | 94 | 0 |
| 10D | 4 | 0 | 94 | 0 |
| 11D | 81 | 7 | 1,228 | 0 |
| 12D | 90 | 0 | 716 | 0 |
| 13D | 0 | 0 | 14 | 0 |
| 14D | 216 | 4 | 486 | 0 |
| 15D | 0 | 0 | 90 | 0 |
| Average | 51 | 1 | 289 | 0 |
| Open lake | | | | |
| 1L | 270 | 50 | 338 | 0 |
| 2L | 40 | 0 | 27 | 4 |
| 3L | 58 | 50 | 68 | 0 |
| 4L | 144 | 27 | 364 | 0 |
| 5L | 94 | 0 | 117 | 0 |
| 6L | 45 | 4 | 31 | 0 |
| 7L | 68 | 31 | 99 | 9 |
| 8L | 216 | 14 | 446 | 0 |
| 9L | 270 | 14 | 148 | 0 |
| 10L | 63 | 31 | 202 | 0 |
| Average | 127 | 22 | 184 | 1 |

* Other genera found but not listed included: *Calopsectra*—99 at 1R, and 4 at 2R; *Polypedilum*—135 at 1R; *Pentaneura*—9 at 14D, and 4 at 7L.

† Station 16D omitted because midges were identified only to family.

tion was at Station 11D, near the center of the Detroit River area and to the east (Fig. 3). Stations with fewer than 300/m² were principally more lakeward or on the west side of the Detroit River area.

The quantitative distribution of midges, as a family, exhibited no consistent correlation with numbers of tubificids. Four of the 13 stations with more than 5,000 worms/m² had a high number of midges (more than the combined station average), and five had fewer than 100 midges/m². Samples from low-worm-count stations also contained both high and low numbers of midge larvae.

The division of the Tendipedidae into the several genera (Table 3) aids in the understanding of the wide variations in abundance of midges both in areas near and more removed from sources of pollution. Only three genera—*Procladius*, *Coelotanypus*, and *Cryptochironomus*—were widely distributed. Representative specimens of *Procladius* and *Coelotanypus* have been determined by LaVerne L. Curry (personal communication) as *P. bellus* and *C. concinnus*, respectively. The midges of the genus *Tendipes*, commonly plentiful in polluted areas, especially in areas with low dissolved oxygen, were neither widely distributed nor abundant.

*Procladius* was the only genus except *Tendipes* that is generally considered to be tolerant of polluted waters. It is often abundant where tubificids are numerous because it feeds on these worms. Surber (1957) found *Procladius* to be the most numerous of the midges in the more polluted areas of several Michigan lakes. Only tubificids, however, were able to survive where pollution was severe. *Procladius* was present at every station of the present study and was most abundant at Station 11D, where 93.3% of the midges were *Procladius* (density of all genera combined, 1,316/m²). At the 13 stations with more than 5,000 tubificids/m², *Procladius* made up 90.6% of the total midges; at four of these, only *Procladius* was found. At stations with fewer than 5,000 tubificids/m², 62.8% were *Procladius*. Although *Procladius* made up a high percentage of the midges in both

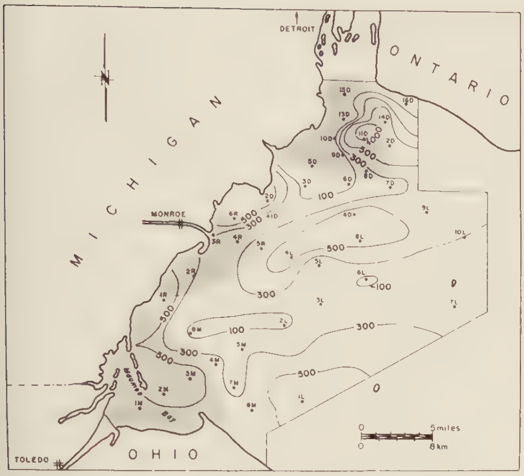

FIG. 3. Distribution of Tendipedidae (no./m²) in western Lake Erie, 1961. Shaded areas are zones of heavy pollution (from Fig. 2).

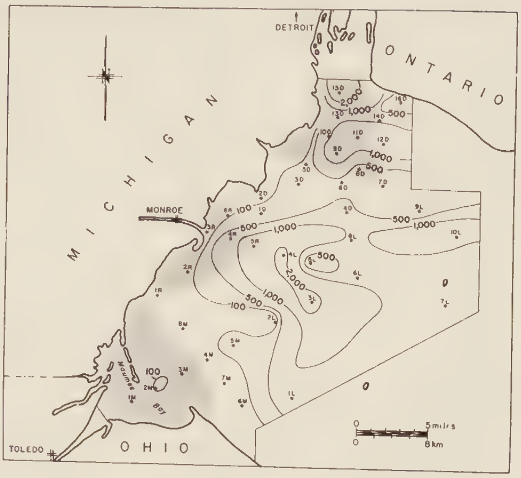

FIG. 4. Distribution of Sphaeriidae (no./m²) in western Lake Erie, 1961. Shaded areas are zones of heavy pollution (from Fig. 2).

situations, the difference appears to be significant. The pollution-tolerant *Procladius* was most abundant at the stations nearest the sources of pollution. At the five stations of the Detroit River area which had more than 5,000 worms/m² but fewer than 100 midges/m² (5D, 9D, 10D, 13D, 15D), all midges except one were *Procladius.*

*Sphaeriidae.* The Sphaeriidae were well represented in the samples; they were more abundant than any group except the tubificids. Fifteen species were collected; Heard (1962) listed 14 as previously known from Lake Erie. Three species—*Pisidium punctatum, Sphaerium (Musculium) lacustre* forma *jayense,* and *Pisidium walkeri*—that were in our samples were not included in Heard's list; and two listed by Heard—*Pisidium idahoense* and *Sphaerium occidentale*—were not taken by us.

Fingernail clams were most abundant near the mouth of the Detroit River and in the open-lake area (Fig. 4). An extensive area of relatively low density extended along the entire Michigan shoreline and included most stations in the Maumee River area, where no fingernail clams were taken at one station and fewer than 15/m² at three others (Table 4). In the Raisin River area fingernail clams were not collected at two stations and the counts were 50/m² or fewer at two others. More than 300/m² were found at 12 of the 16 stations in the Detroit River area. Population density in the open-lake area exceeded 400/m² at seven of 10 stations.

The number of species at different stations ranged from one (several stations) to 13 at 5R (Table 4). Ten species appeared in samples from 10 or more stations and five (*Pisidium casertanum, P. compressum, P. nitidum, Sphaerium corneum,* and *S. transversum*) from more than 20. The five most widely distributed species, and *Sphaerium striatinum* contributed 89.7% of all fingernail clams.

The geographic distribution of only two species, *Sphaerium corneum* and *S. transversum,* appeared to be affected by pollution, as determined by worm counts. *S. transversum* was cited frequently by Ingram (1957) as a molluscan indicator of pollution; S. *corneum* is not generally recognized as a clean-water form and has been listed by investigators as tolerant of some pollution (Hynes 1960; Ingram 1957; Whipple 1948). Its distribution in this study indicated that it is considerably less tolerant than S. *transversum.*

Wide differences existed in the respective percentage contribution of S. *corneum* (Fig. 5) and S. *transversum* at stations with

TABLE 4. *Density (no./m²) of different species of Sphaeriidae in western Lake Erie, 1961**

| Area and station | Genus and species† | | | | | | | | | | | Unidentified |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | *Pisidium* | | | | | | | *Sphaerium* | | | | |
| | *amnicum* | *casertanum* | *compressum* | *henslowanum* | *nitidum* | *punctatum* | *subtruncatum* | *corneum* | *lacustre* | *striatinum* | *transversum* | |
| Maumee River | | | | | | | | | | | | |
| 2M | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 85 | 23 |
| 3M | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 14 | 67 |
| 4M | 0 | 0 | 9 | 4 | 9 | 0 | 0 | 14 | 0 | 0 | 9 | 0 |
| 5M | 0 | 19 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 29 | 77 | 10 |
| 6M | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 14 |
| 7M | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 4 | 0 | 0 | 0 |
| 8M | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 14 | 0 |
| Raisin River‡ | | | | | | | | | | | | |
| 1R | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 14 |
| 4R | 0 | 67 | 150 | 183 | 67 | 166 | 25 | 0 | 0 | 0 | 58 | 0 |
| 5R | 40 | 284 | 284 | 85 | 104 | 63 | 9 | 108 | 40 | 9 | 202 | 14 |
| Detroit River‡ | | | | | | | | | | | | |
| 1D | 9 | 14 | 9 | 0 | 4 | 4 | 4 | 9 | 0 | 4 | 9 | 54 |
| 2D | 4 | 0 | 14 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 9 | 4 |
| 3D | 0 | 54 | 45 | 18 | 14 | 0 | 36 | 0 | 81 | 0 | 94 | 0 |
| 4D | 0 | 63 | 14 | 23 | 18 | 18 | 4 | 405 | 9 | 0 | 4 | 0 |
| 5D | 0 | 4 | 0 | 4 | 4 | 18 | 4 | 0 | 23 | 0 | 14 | 27 |
| 6D | 0 | 90 | 4 | 23 | 14 | 27 | 18 | 176 | 4 | 0 | 54 | 0 |
| 7D | 0 | 94 | 23 | 0 | 14 | 4 | 0 | 94 | 18 | 36 | 27 | 0 |
| 8D | 0 | 45 | 18 | 0 | 9 | 0 | 0 | 45 | 0 | 176 | 27 | 0 |
| 9D | 0 | 162 | 126 | 0 | 4 | 40 | 0 | 90 | 77 | 77 | 1,040 | 0 |
| 10D | 0 | 256 | 40 | 4 | 131 | 135 | 18 | 4 | 117 | 0 | 243 | 0 |
| 11D | 24 | 321 | 72 | 160 | 7 | 48 | 0 | 169 | 95 | 657 | 257 | 0 |
| 12D | 17 | 214 | 197 | 98 | 44 | 5 | 0 | 324 | 5 | 457 | 317 | 0 |
| 13D | 0 | 135 | 94 | 0 | 216 | 31 | 18 | 0 | 50 | 0 | 131 | 0 |
| 15D | 0 | 126 | 45 | 0 | 31 | 27 | 0 | 9 | 85 | 27 | 2,511 | 0 |
| 16D | 0 | 23 | 40 | 27 | 72 | 0 | 0 | 9 | 0 | 0 | 18 | 0 |
| Open Lake‡ | | | | | | | | | | | | |
| 2L | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 4 | 0 | 27 |
| 3L | 0 | 99 | 202 | 0 | 72 | 9 | 0 | 1,256 | 0 | 756 | 9 | 117 |
| 4L | 0 | 176 | 275 | 9 | 94 | 14 | 0 | 1,174 | 68 | 162 | 148 | 0 |
| 5L | 0 | 27 | 77 | 0 | 23 | 4 | 0 | 54 | 0 | 45 | 9 | 0 |
| 6L | 0 | 9 | 45 | 0 | 14 | 0 | 14 | 486 | 0 | 50 | 0 | 0 |
| 7L | 0 | 27 | 27 | 0 | 0 | 0 | 0 | 378 | 0 | 41 | 0 | 0 |
| 8L | 0 | 54 | 45 | 4 | 72 | 40 | 0 | 634 | 4 | 31 | 77 | 0 |
| 9L | 0 | 0 | 81 | 0 | 4 | 0 | 0 | 40 | 0 | 4 | 0 | 18 |
| 10L | 0 | 148 | 104 | 0 | 27 | 4 | 9 | 688 | 0 | 117 | 14 | 0 |

* Other species found but not listed included: *P. fallax*—10 at 12D and 4 at 16D; *P. lilljeborgi*—4 at 1D and 24 at 11D; *P. variabile*—4 at 5R; *P. walkeri*—4 each at 5R, 2D, and 9D and 9 each at 6D and 3L.

† None of these organisms was found at 1M (Maumee River), 2R, and 3R (Raisin River).

‡ Stations 6R, 14D, and 1L omitted because organisms were identified only to family.

more than 5,000 tubificids/m², as compared with stations that had less than this number (Table 5). *S. corneum* comprised 27.7% of the total number of fingernail clams at all stations, but made up 44.6% of the clams at the stations with fewer than 5,000 worms/m² and only 3.5% at the 13 stations with high worm counts. In contrast, *S. transversum* (which contributed 24.6% of the total number of clams at all stations) accounted for 47.7% of the clams at the high-worm-count stations and only 8.3% at stations with few worms. Similar differences existed between these species at stations with more than 500 fingernail clams/m² in the Detroit River area as compared with open-lake stations

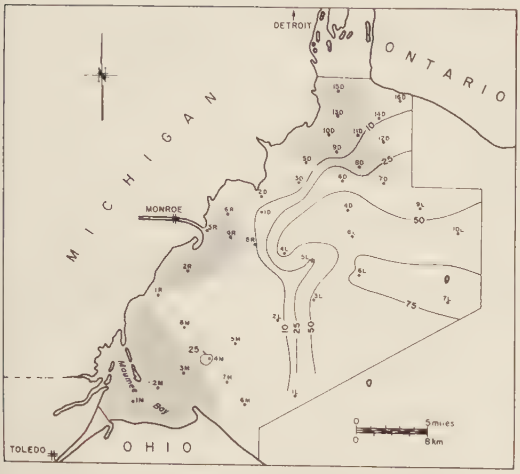

FIG. 5. Distribution of *Sphaerium corneum* in western Lake Erie, 1961 (isopleths show percentage of total number of Sphaeriidae). Shaded areas are zones of heavy pollution (from Fig. 2).

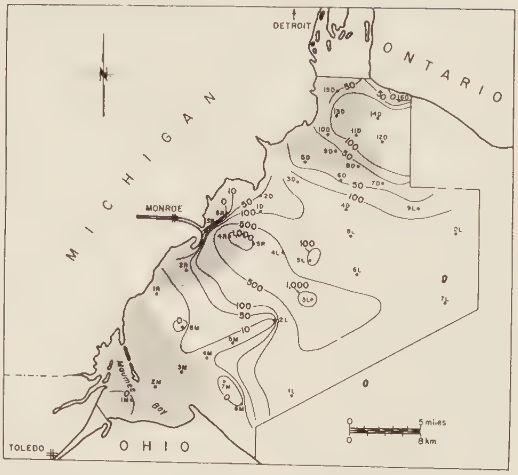

FIG. 6. Distribution of Gastropoda (no./m²) in western Lake Erie, 1961. Shaded areas are zones of heavy pollution (from Fig. 2).

where clams were equally numerous (Table 5).

*Gastropoda.* The snails were characterized by wide distribution (collected at 33 stations) but relatively low abundance (Fig. 6). The population density exceeded 200/m² at six stations, was 50 to 200/m² at 15, and was less than 50/m² at 19. The stations with the highest counts (more than 500/m²) were in a narrow band from a station near the mouth of the Raisin River (4R) southeasterly toward the center of the open-lake area (3L). The Maumee River area had almost no gastropods—24 dredge hauls yielded only seven individuals. The remaining stations with few snails were near the mouth of the Raisin River and in the western portion of the Detroit River area. The distribution of snails was similar to that of fingernail clams and naiads (discussed in a later section). All three molluscs were scarce or lacking in the Maumee Bay area, in inshore waters along the Michigan shore, and along the west side of the Detroit River area; they were most abundant in the open lake, east of the mouth of the Raisin River, and along the east side of the Detroit River area.

The Gastropoda included a few pulmonate snails of the genera *Helisoma* and *Physa*, and several species of operculate snails—*Amnicola* spp., *Bulimus tentaculatus*, *Valvata sincera*, and *V. tricarinata* (Table 6). The operculate snails made up 99% of the total number. *B. tentaculatus* was the most numerous (51% of the total) and most widely distributed (collected at 26 stations).

Operculate snails generally are scarce in polluted areas, but a few species have been reported to survive to at least some degree in polluted habitats (Wurtz, *cited in* Ingram 1957). The four most abundant forms in our study are not considered highly tolerant, although their distribution appeared to vary significantly in relation to degree of pollution. At stations where the worm population was dense, *V. sincera* was much more abundant than would be expected by chance—about 2.5 times more plentiful than the average for all stations (data combined), and 5 times more abundant than at the stations with low worm counts (Table 7). The other three species were relatively less numerous at high-worm-count stations than at others. At stations where snails were abundant (more than 500/m²), *V. sincera* contributed 45% of the total in the Raisin River area, but less than 2% in the open-

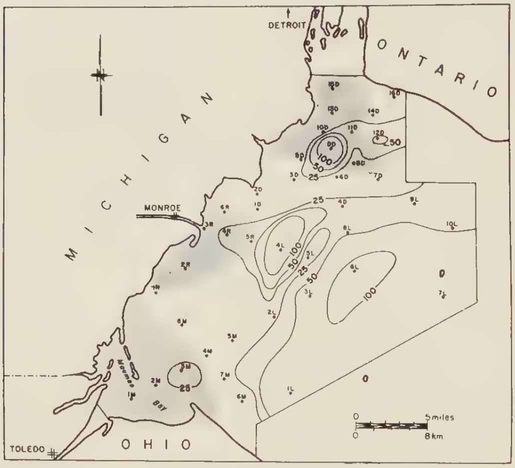

FIG. 7. Distribution of Hirudinea (no./m²) in western Lake Erie, 1961. Shaded areas are zones of heavy pollution (from Fig. 2).

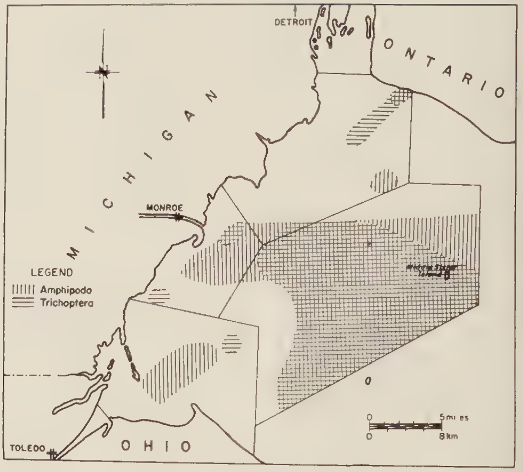

FIG. 8. Distribution of Trichoptera and Amphipoda (*Gammarus*) in western Lake Erie, 1961.

lake area. It appears that this species is more tolerant of pollution than any other snail that occurred in large numbers. It was not listed by Wright (1955) in the 1928–1930 study or by Brown (1953) in the 1951 survey of the Maumee Bay area; Wood (1963) found only four specimens in extensive sampling in the western basin. *V. sincera* apparently has widened its distribution and increased its numbers in the past decade.

### *Other taxonomic groups*

*Hirudinea.* The distribution of the leeches was similar to that of molluscs; the areas with relatively high numbers (over 25/m² for leeches) and low numbers of each form were essentially the same (Fig. 7). Concentrations of leeches were high east of the Raisin River and near the center of the Detroit River area, and low along the Michigan shore and in the Maumee River area.

TABLE 5. *Percentage contribution of selected species of Sphaeriidae at different groups of sampling stations*

| Stations | Genus and species | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | *Pisidium* | | | | | | *Sphaerium* | | | |
| | *casertanum* | *compressum* | *henslowanum* | *nitidum* | *punctatum* | *subtruncatum* | *corneum* | *lacustre* | *striatinum* | *transversum* |
| All stations | 11.3 | 9.2 | 2.9 | 4.8 | 3.0 | 0.7 | 27.7 | 3.1 | 12.1 | 24.6 |
| Stations with more than 5,000 worms/m² | 12.2 | 6.0 | 3.8 | 5.1 | 5.1 | 0.7 | 3.5 | 4.9 | 10.2 | 47.7 |
| Stations with less than 5,000 worms/m² | 10.6 | 11.4 | 2.2 | 4.6 | 1.5 | 0.7 | 44.6 | 1.8 | 13.3 | 8.3 |
| Stations in Detroit River area with more than 500 fingernail clams/m² | 15.0 | 7.3 | 2.5 | 8.5 | 4.3 | 0.8 | 6.0 | 5.5 | 12.0 | 38.0 |
| Stations in open-lake area with more than 500 fingernail clams/m² | 9.5 | 11.0 | 4.8 | 4.9 | 4.6 | 1.0 | 50.0 | 1.0 | 8.0 | 5.3 |

TABLE 6. *Density (no./$m^2$) of different species of Gastropoda in western Lake Erie, 1961**

| Area and station | Species | | | | |
|---|---|---|---|---|---|
| | *Amnicola* species | *Bulimus tentaculatus* | *Campeloma decisum* | *Valvata sincera* (sens. lat.) | *Valvata tricarinata* (sens. lat.) |
| Maumee River | | | | | |
| 1M | 0 | 0 | 0 | 0 | 0 |
| 2M | 9 | 0 | 0 | 0 | 0 |
| 3M | 0 | 4 | 0 | 4 | 0 |
| 4M | 0 | 9 | 0 | 0 | 0 |
| 5M | 0 | 4 | 0 | 0 | 0 |
| 6M | 0 | 0 | 0 | 0 | 0 |
| 7M | 0 | 0 | 0 | 0 | 0 |
| 8M | 0 | 0 | 0 | 0 | 0 |
| Raisin River | | | | | |
| 1R | 0 | 0 | 4 | 0 | 0 |
| 2R | 0 | 0 | 23 | 0 | 0 |
| 3R | 0 | 0 | 0 | 0 | 0 |
| 4R | 14 | 392 | 4 | 608 | 4 |
| 5R | 72 | 230 | 0 | 310 | 378 |
| 6R | 0 | 0 | 0 | 0 | 0 |
| Detroit River† | | | | | |
| 1D | 0 | 23 | 0 | 27 | 4 |
| 2D | 0 | 23 | 9 | 18 | 0 |
| 3D | 14 | 58 | 0 | 23 | 31 |
| 4D | 31 | 63 | 0 | 0 | 27 |
| 5D | 0 | 0 | 0 | 4 | 0 |
| 6D | 4 | 9 | 0 | 9 | 18 |
| 7D | 4 | 14 | 0 | 4 | 18 |
| 8D | 0 | 0 | 0 | 27 | 14 |
| 9D | 0 | 23 | 0 | 4 | 14 |
| 10D | 4 | 4 | 0 | 23 | 45 |
| 11D | 27 | 88 | 7 | 0 | 20 |
| 12D | 0 | 405 | 0 | 0 | 45 |
| 13D | 0 | 0 | 0 | 135 | 50 |
| 15D | 36 | 4 | 0 | 9 | 0 |
| 16D | 0 | 0 | 0 | 0 | 0 |
| Open lake | | | | | |
| 1L | 27 | 117 | 0 | 0 | 45 |
| 2L | 0 | 4 | 0 | 0 | 0 |
| 3L | 90 | 1,026 | 0 | 0 | 45 |
| 4L | 148 | 230 | 0 | 27 | 126 |
| 5L | 4 | 36 | 0 | 0 | 50 |
| 6L | 0 | 104 | 0 | 0 | 40 |
| 7L | 4 | 85 | 0 | 0 | 50 |
| 8L | 40 | 63 | 0 | 0 | 23 |
| 9L | 0 | 50 | 0 | 4 | 0 |
| 10L | 40 | 50 | 0 | 40 | 27 |

* Other species found but not listed included: *Helisoma* species—4 each at 5R and 4L and 9 at 4R; *Physa* species—4 each at 4D and 10D; *Somatogyrus subglobosus*—4 each at 4D and 6D.

† Station 14D omitted because organisms were identified only to order.

The tolerance of leeches to pollution varies widely among species. Several species are listed as both polysaprobic and mesosaprobic by Kolkwitz and Marsson (*in* Whipple 1948). Since the numbers of leeches tended to increase lakeward, they apparently were affected adversely by polluted conditions near the river mouths. The occurrence of more than 30 leeches/$m^2$ at only one of the stations with high worm counts (9D) also indicated less favorable conditions near the rivers.

*Amphipoda.* The amphipod, *Gammarus* sp., was taken at 16 stations but never in large numbers. The highest concentrations were at open-lake Stations 1L, 3L, and 6L; the count exceeded 100/$m^2$ only at 3L.

The value of this amphipod as an indicator of environmental conditions is little understood. It does not tolerate severe conditions but is able to withstand some types of pollution. Gammarids were present at four of the 13 stations with high worm counts and at eight of 10 open-lake stations (Fig. 8). They made up only 2% of the total number of organisms (excluding oligochaetes) at the open-lake stations, as compared to over 10% reported by Wood (1963). Their relative abundance apparently has been reduced even at the stations far removed from the river mouths.

*Ephemeroptera.* The catastrophic depletion of the once abundant mayfly (*Hexagenia*) in western Lake Erie in 1953 and its subsequent recovery were reported by Britt (1955*a*, *b*). Samples from the island area subsequent to the recovery showed that the population of mayflies was again reduced (Beeton 1961). The mayfly population also has been reduced almost to extinction in the area of Lake Erie included in the present study. The total number of *Hexagenia* nymphs collected was 10, none of which would have matured until the following year.

The seven stations where mayflies were found were well scattered; at least one was located in each of the four geographic areas. Amphipods and caddisfly larvae or both also were present at all of the stations where mayflies were found (except 12D).

TABLE 7. *Percentage contributions of selected species of Gastropoda at different groups of sampling stations*

| Stations | *Amnicola* spp. | *Bulimus tentaculatus* | *Valvata sincera* (sens. lat.) | *Valvata tricarinata* (sens. lat.) |
|---|---|---|---|---|
| All stations | 9.3 | 51.0 | 20.9 | 17.6 |
| Stations with more than 5,000 worms/m² | 5.6 | 31.9 | 50.5 | 9.1 |
| Stations with less than 5,000 worms/m² | 10.6 | 57.8 | 10.2 | 20.6 |
| Stations in Raisin River area with more than 500 gastropods/m² | 4.2 | 30.5 | 45.0 | 18.7 |
| Stations in open-lake area with more than 500 gastropods/m² | 14.0 | 73.8 | 1.6 | 10.0 |

*Hexagenia* nymphs were taken at two stations with more than 5,000 tubificids/m² (Table 2).

*Trichoptera.* The distribution of caddisfly larvae was similar to that of the gammarids except that caddisflies were more common near the Ontario shore and the gammarids more widely distributed in the Maumee River area (Fig. 8). Trichoptera larvae were collected in limited numbers at 13 stations. They were confined primarily to the open-lake area and were lacking in the Maumee River area and at most stations in the Detroit River area (Fig. 8). Caddisfly larvae appeared at only two of the 13 stations with high worm counts, but at seven of the 10 open-lake stations. Although caddisfly larvae were taken at about one-third of the stations, only 35 individuals were obtained in the entire study. This "clean-water" organism thus is scarce in western Lake Erie.

Two genera of Trichoptera were represented. *Phylocentropus* sp. was present at three stations and *Oecetis* sp. at 11; the two genera were taken together at only one (4L). Wood (1963) also found these two genera (although *Phylocentropus* was represented by only one specimen); Brown (1953) collected only *Oecetis.*

*Chaoborus.* Larvae of the phantom midge were collected in only limited numbers (total of 16) and in a restricted area (only at Stations 1M, 2M, and 3M). Wright (1955) did not list *Chaoborus* as occuring in 1929–1930; Brown (1953) and Wood (1963) found a few individuals in their more recent sampling.

*Unionidae.* The presence of naiads is generally considered to indicate clean water. Ingram (1957, p. 94) stated, ". . . their presence typically indicates good dissolved oxygen and attendant physical and chemical conditions associated with unpolluted water." The 20 stations at which naiads were collected during the present study included all but one of the open-lake stations, but only four stations with high numbers of worms. Naiads were lacking in most of the area along the Michigan shore and at

TABLE 8. *Species of Unionidae taken in western Lake Erie in 1961 showing collecting stations and (in parentheses) density (no./m²)*

| Species | Stations and density |
|---|---|
| *Anodonta grandis* | 7M (4), 7D (4), 1L (4), 3L (9), 7L (9) |
| *Elliptio dilatatus* | 3L (4) |
| *Fusconaia flava* | 3L (4) |
| *Lampsilis siliquoidea* | 5R (9), 7D (4), 11D (7), 3L (9), 5L (4), 7L (4), 8L (14) |
| *Lampsilis ventricosa* | 2D (4), 4D (4) |
| *Leptodea fragilis* | 6L (4) |
| *Leptodea laevissima* | 4L (4), 9L (4) |
| *Ligumia nasuta* | 4R (4), 5R (4), 4D (4), 5D (4), 3L (4), 4L (4), 6L (14), 8L (14) |
| *Proptera alata* | 6L (4) |
| Other Unionidae* | |
| Immature | 2M (4), 4R (4), 5R (14), 1L (4), 8L (4), 10L (4) |
| Mature | 5M (9), 14D (4) |

* Identified only to family.

TABLE 9. *Average density (no./m²) of bottom organisms in western Lake Erie, 1930 and 1961 and ratio of numbers, 1961 to 1930 (All stations combined)*

| Organism | Number of stations compared | Year | | Ratio of numbers (1961/1930) |
|---|---|---|---|---|
| | | 1930 | 1961 | |
| Oligochaeta | 33 | 677 | 5,949 | 8.79 |
| *Hexagenia* | 33 | 139 | 1 | 0.01 |
| Tendipedidae | 23 | 73 | 322 | 4.41 |
| Sphaeriidae | 23 | 221 | 438 | 1.98 |
| Gastropoda | 16 | 40 | 221 | 5.52 |

five of the eight stations off the Maumee River (Fig. 9).

The greater abundance in the open-lake (and consequently deeper) areas conflicts with Baker's (1928, p. 26) statement that, "The great majority of naiads live in comparatively shallow water from a foot to six feet in depth. More rarely they descend to depths as great as 25 feet. Records of fresh-water mussels from greater depths than 25 feet are to be viewed with suspicion." We not only found naiads at all stations at which the water was deeper than 7.6 m (25 feet) but these stations included the areas of greatest concentration.

The 9 species that were identified (Table 8) included three of 11 found by Wright (1955), eight of the 14 collected by Wood (1963), and one (*Leptodea laevissima*) not listed for Lake Erie by either Wright or Wood. *Ligumia nasuta* and *Lampsilis siliquoidea* were the most widely distributed (taken at eight and seven stations, respectively) and the most abundant. Five species were taken at Station 3L and three at 6L. Other stations yielded only one or two species.

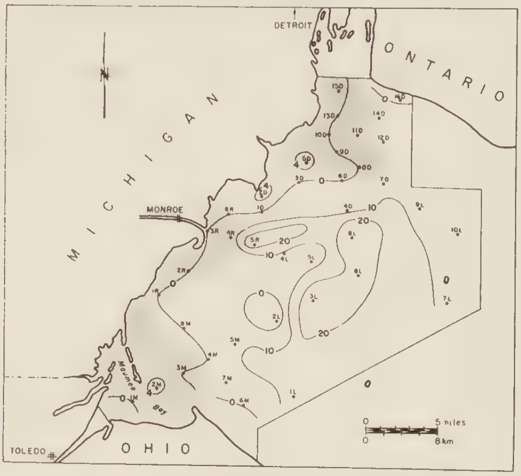

FIG. 9. Distribution of Unionidae (no./m²) in western Lake Erie, 1961. Shaded areas are zones of heavy pollution (from Fig. 2).

## CHANGES IN THE DISTRIBUTION AND ABUNDANCE OF BOTTOM FAUNA FROM 1930 TO 1961

Direct comparisons between the 1930 collections of bottom fauna in western Lake Erie (Wright 1955) and our 1961 collections are possible for oligochaetes and mayflies at 33 stations, for midges and fingernail clams at 23 stations, and for gastropods at 16 stations. Methods were similar in both studies except that the 1961 samples were examined under a dissecting microscope and the organisms were counted individually. In 1930, organisms were counted without magnification and collections were subsampled when the number of tubificids was large.

Changes have been extensive in the distribution and abundance of organisms in the several taxonomic groups (Table 9). In the area as a whole (data combined for all stations) the number of fingernail clams in 1961 was nearly double that of 1930, the midges were 4.4 times, the snails were 5.5 times, and the tubificids were nearly 9 times more abundant. Nymphs of the burrowing mayfly decreased to 1% of the former numbers—from an average of 139/m² in 1930 to 1/m² in 1961. The number of tubificids increased at all stations except 1M, and midges increased at all stations except 5D and 6D, but the number of fingernail clams was reduced or unchanged at 10 of 23 stations and the number of gastropods at five of 16. The decrease in mayflies and the increases in tubificids and midges were the most striking and widespread changes that occurred during the 31 years between the studies.

Pollution expanded sharply between 1930 and 1961. For all areas combined, the area

TABLE 10. *Area ($km^2$) of different zones of pollution and (in parentheses) percentage of total area within each zone, for four sections of western Lake Erie, 1930 and 1961**

| Pollution zone | Section of lake and year | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Maumee River | | Raisin River | | Detroit River | | Open lake | | Total | |
| | 1930 | 1961 | 1930 | 1961 | 1930 | 1961 | 1930 | 1961 | 1930 | 1961 |
| Light | 39<br>(19) | 2<br>(1) | 30<br>(29) | 0<br>(0) | 122<br>(52) | 27<br>(12) | 0<br>(0) | 236<br>(50) | 191<br>(19) | 265<br>(26) |
| Moderate | 13<br>(6) | 99<br>(48) | 2<br>(2) | 55<br>(53) | 31<br>(13) | 124<br>(53) | 0<br>(0) | 239<br>(50) | 46<br>(4) | 517<br>(51) |
| Heavy | 25<br>(12) | 107<br>(51) | <1<br>(1) | 48<br>(47) | 0<br>(0) | 83<br>(35) | 0<br>(0) | 0<br>(0) | 26<br>(3) | 238<br>(23) |
| Total | 77<br>(37) | 208<br>(100) | 33<br>(32) | 103<br>(100) | 153<br>(65) | 234<br>(100) | 0<br>(0) | 475<br>(100) | 263<br>(26) | 1,020<br>(100) |

* Areas determined by planimeter from Fig. 2 for 1961 and from Wright (1955) for 1930.

of light pollution (100 to 999 worms/$m^2$) included 191 $km^2$ in 1930 and 265 $km^2$ in 1961 (Table 10). The zone of moderate pollution (1,000 to 5,000 worms/$m^2$) increased from 46 $km^2$ in 1930 to 517 $km^2$ in 1961 (Fig. 10). The zone of heavy pollution (more than 5,000 worms/$m^2$) covered an area of 26 $km^2$ in 1930 and 238 $km^2$ in 1961 (Fig. 11). The total area classed as polluted in 1930 was 263 $km^2$, or 26% of the area sampled. The entire area (1,020 $km^2$) was classed as polluted in 1961—26% lightly polluted, 51% moderately polluted, and 23% heavily polluted (Table 10). If this trend continues, the entire western basin will have bottom fauna that, in 1930, was characteristic only of the areas near the mouths of the rivers.

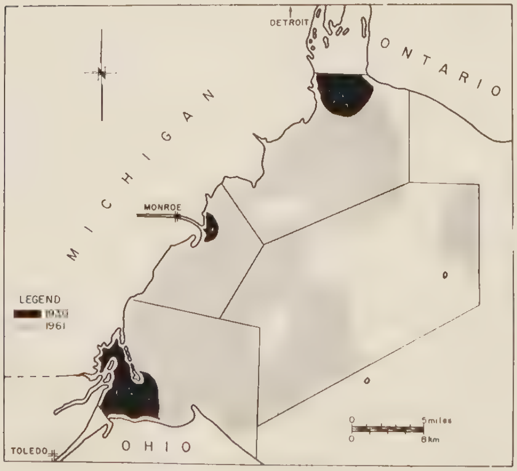

FIG. 10. Zones of moderate pollution (1,000 to 5,000 Oligochaeta/$m^2$) in western Lake Erie, 1930 and 1961. The shaded areas include also the zones of heavy pollution shown in Fig. 11.

Changes in bottom fauna in the four geographic subdivisions of the study depart greatly from those in the area considered in its entirety. The comparisons of conditions in 1930 and 1961 in each subdivision are, therefore, considered the most meaningful in determining the degree and direction of change.

### *Maumee River area*

Wright (1955) described the Maumee River area in 1930 as heavily polluted (more than 5,000 Tubificidae/$m^2$) in the river channel and lakeward 5.6 km to Station 1M; moderately polluted (1,000–5,000 worms/$m^2$) from Station 1M for a distance of 2.4 km to Station 2M; and lightly polluted (100–999 worms/$m^2$) for 6.4 km to Station 4M. Brown (1953) found that in 1951 the zone of heavy pollution extended 9 km farther out; moderate pollution, 13 km; and light pollution, 10 km farther. The zone of heavy pollution in 1961 (Fig. 11) included Stations 1M, 2M, 3M (Table 11), and thus covered about the same area as in 1951. All stations in the Maumee River area were within either the zone of heavy or moderate pollution in 1961 (Fig. 10).

The number of tubificid worms/$m^2$ at the eight stations in the Maumee River area

TABLE 11. *Density (no./m²) of bottom organisms in 1930 and 1961 in the Maumee River area*

| Station number | Oligochaeta | | *Hexagenia* | | Tendipedidae | | Sphaeriidae | |
|---|---|---|---|---|---|---|---|---|
| | 1930 | 1961 | 1930 | 1961 | 1930 | 1961 | 1930 | 1961 |
| 1M | 11,310 | 9,004 | 2 | 0 | —* | 378 | —* | 0 |
| 2M | 1,040 | 7,168 | 37 | 0 | 92 | 797 | 961 | 108 |
| 3M | 334 | 10,300 | 34 | 0 | —* | 675 | —* | 81 |
| 4M | 504 | 2,781 | 63 | 14 | 98 | 324 | 332 | 45 |
| 5M | 7 | 1,714 | 402 | 0 | —* | 216 | —* | 135 |
| 6M | 0 | 1,984 | 94 | 0 | 148 | 351 | 14 | 14 |
| 7M | 0 | 4,306 | 270 | 0 | 68 | 256 | 14 | 4 |
| 8M | 68 | 3,010 | 81 | 0 | 14 | 68 | 1,134 | 14 |
| Mean number† | 1,658 | 5,033 | 123 | 1.8 | 84 | 359 | 491 | 37 |
| 1961 to 1930 ratio | 3.04:1 | | 0.01:1 | | 4.27:1 | | 0.08:1 | |

* No data.
† Based on stations with data available for both years.

increased approximately three times between 1930 and 1961. The expansion of the pollution zones in this section appears to be toward the northwest and northeast rather than directly lakeward. Studies by this laboratory of currents in Maumee Bay have shown that water moves counterclockwise in the bay and flows out past Cedar Point in the northeast corner of the bay. This water movement undoubtedly limits the lakeward influence of the river.

*Hexagenia* nymphs in the Maumee River area were moderately numerous (2 to 94/m²) at most stations and abundant at two stations (402/m² at 5M and 270/m² at 7M) in 1930 (Table 11). Only three specimens were taken in 1961 (Station 4M). Wood (1963) collected only two nymphs from Maumee Bay in 1951–1952, and Brown (1953) reported *Hexagenia* in only one of 73 samples in 1951 from the Maumee River and Maumee Bay. Conditions unfavorable to *Hexagenia* apparently developed in the Maumee River area prior to 1950.

The abundance of midge larvae increased more than fourfold (about the same as in all sections combined) between 1930 and 1961; the number/m² at different stations ranged from 14 to 148 in 1930 and from 68 to 797 in 1961 (Table 11). Environmental conditions obviously are more favorable for midges now than in the past—particularly for *Procladius*, which comprised more than 90% of the total at the three stations within the bay (1M, 2M, 3M). Oligochaetes and midge larvae dominated the bottom fauna of the Maumee River area in 1961; whereas oligochaetes, mayflies, and fingernail clams were dominant in 1930.

The average number of fingernail clams/m² decreased to 8% of their former abundance in the Maumee River area between 1930 and 1961. The number either decreased or remained unchanged at all stations in the Maumee River area, but decreased at only two other stations (3R, 5D) throughout the rest of the study area. One explanation for the contrast is that the rate

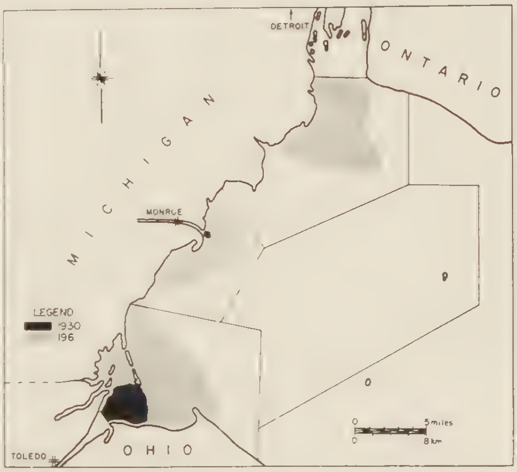

FIG. 11. Zones of heavy pollution (more than 5,000 Oligochaeta/m²) in western Lake Erie, 1930 and 1961.

TABLE 12. *Density (no./m²) of bottom organisms in 1930 and 1961 in the Raisin River area*

| Station number | Oligochaeta |  | *Hexagenia* |  | Tendipedidae |  | Sphaeriidae |  | Gastropoda |  |
|---|---|---|---|---|---|---|---|---|---|---|
|  | 1930 | 1961 | 1930 | 1961 | 1930 | 1961 | 1930 | 1961 | 1930 | 1961 |
| 1R | 0 | 4,185 | 40 | 0 | 540 | 634 | 14 | 14 | —* | 4 |
| 2R | 0 | 9,328 | 0 | 4 | 68 | 297 | 0 | 0 | 14 | 23 |
| 3R | 5,800 | 13,311 | 0 | 0 | 135 | 310 | 109 | 0 | 54 | 0 |
| 4R | 104 | 10,854 | 8 | 0 | 55 | 162 | 46 | 716 | 105 | 1,040 |
| 5R | 14 | 1,026 | 27 | 0 | 148 | 446 | 0 | 1,242 | 27 | 999 |
| Mean number† | 1,184 | 7,741 | 15 | 0.8 | 189 | 370 | 34 | 394 | 51 | 516 |
| 1961 to 1930 ratio | 6.54:1 |  | 0.05:1 |  | 1.96:1 |  | 11.59:1 |  | 10.12:1 |  |

* No data.
† Based on stations with data available for both years.

of deposition of silt in the Maumee River area (due to frequent dredging of the ship channel and the river's heavy silt load during periods of high flow) is sufficiently great to smother the clams. A second possible explanation for the scarcity of molluscs is the presence of a chemical toxic to this group but relatively harmless to midge larvae.

### *Raisin River area*

Bottom fauna in the Raisin River area varied greatly among the five stations, both quantitatively and qualitatively. Organisms from Station 3R at the mouth of the Raisin River were limited to oligochaetes and midge larvae (97% *Procladius*) in 1961 (Table 12). In contrast, the composition of the fauna at Station 5R, less than 7 km away, was extremely diverse; in addition to oligochaetes and leeches, the collection included *Gammarus*, 2 species of naiads, 4 of midges, 5 of snails, and 12 species of fingernail clams. The fauna at Station 4R, halfway between 3R and 5R, also included several species, although the worm count was over 13,000/m².

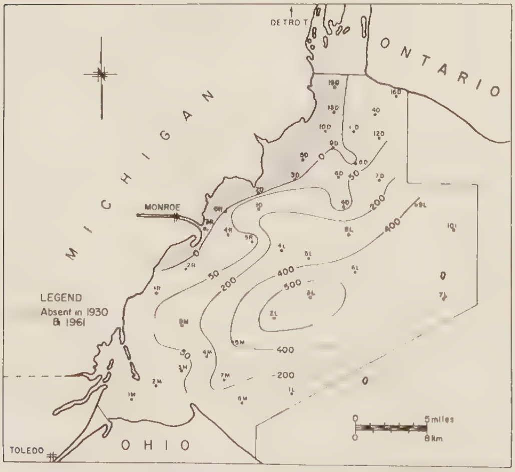

FIG. 12. Distribution of *Hexagenia* (no./m²) in western Lake Erie, 1930.

The zone of heavy pollution in 1930 included only a small area of less than 1 km² at the mouth of the Raisin River. In 1961 the zone extended lakeward to a point between Stations 4R and 5R and along the Michigan shore to Station 1R (Fig. 11), an area of 48 km². In 1930 the zone of moderate pollution covered only 2 km² and was confined to the mouth of the river; in 1961 this zone included all stations in the area (Fig. 10).

*Hexagenia* nymphs were not abundant in 1930, but were present in moderate numbers at three stations (Table 12). Only a single specimen was collected in 1961.

The increase in the number of Tendipedidae/m² between 1930 and 1961 was less off the Raisin River than in the other three areas. The average number of midge larvae/m² in 1930 was more than twice as great as in any other area. The environmental conditions in 1961 apparently still were favorable to this group, although only *Procladius* appeared in substantial numbers at the mouth of the Raisin River.

The number of fingernail clams/m² either remained the same or decreased at three stations but increased substantially at the

TABLE 13. *Density (no./m²) of bottom organisms in 1930 and 1961 in the Detroit River area*

| Station number | Oligochaeta | | *Hexagenia* | | Tendipedidae | | Sphaeriidae | | Gastropoda | |
|---|---|---|---|---|---|---|---|---|---|---|
| | 1930 | 1961 | 1930 | 1961 | 1930 | 1961 | 1930 | 1961 | 1930 | 1961 |
| 1D | 0 | 594 | 162 | 0 | 68 | 189 | 28 | 126 | 54 | 54 |
| 2D | 0 | 4,347 | 0 | 0 | 0 | 648 | 14 | 36 | 40 | 50 |
| 3D | 0 | 1,066 | 0 | 0 | 0 | 50 | 108 | 338 | 162 | 126 |
| 4D | 14 | 1,256 | 21 | 0 | 0 | 540 | 54 | 554 | 0 | 131 |
| 5D | 122 | 5,008 | 0 | 0 | 54 | 4 | 324 | 99 | 54 | 4 |
| 6D | 221 | 1,593 | 13 | 0 | 54 | 50 | 126 | 418 | 5 | 45 |
| 7D | 0 | 2,781 | 176 | 0 | —* | 230 | —* | 310 | —* | 40 |
| 8D | 189 | 13,014 | 0 | 0 | —* | 270 | —* | 324 | —* | 40 |
| 9D | 205 | 20,952 | 0 | 0 | 60 | 94 | 1,108 | 1,620 | 60 | 40 |
| 12D | 168 | 3,564 | 7 | 9 | —* | 810 | —* | 1,688 | —* | 446 |
| 13D | 1,500 | 39,164 | 0 | 0 | 9 | 18 | 374 | 675 | 61 | 189 |
| 15D | 702 | 14,688 | 0 | 0 | —* | 90 | —* | 2,862 | —* | 50 |
| Mean number† | 260 | 9,002 | 32 | 0.75 | 31 | 199 | 267 | 483 | 54 | 80 |
| 1961 to 1930 ratio | 34.62:1 | | 0.02:1 | | 6.42:1 | | 1.81:1 | | 1.48:1 | |

* No data.
† Based on stations with data available for both years.

other two. The area in this section with few clams is continuous with the Maumee River area in which clams are scarce. Wright did not take fingernail clams at Station 5R, but the 1961 collections indicated a density of 1,242/m²; the increase also was large at Station 4R (from 46 to 716/m²).

The changes in numbers of gastropods were similar to those for fingernail clams.

### *Detroit River area*

No part of the Detroit River area was heavily polluted in 1930, but 83 km² was so designated in 1961 (Fig. 11). At stations where no tubificids were taken in 1930, the density in 1961 ranged as high as 4,300/m² (Table 13). Samples from only one station (13D) indicated a density of more than 1,000 worms/m² in 1930, but this number was exceeded at all stations (except 1D) in the section in 1961. The greatest increases in tubificids were at a series of stations extending from the mouth of the river (15D) southerly toward the geographic center of the area (8D—*see* Fig. 2). All of these stations were west of the main flow of the Detroit River but in the area of greatest pollution according to findings of the International Joint Commission (1951) and unpublished chemical data of this laboratory.

The zone of moderate pollution increased from an isolated area near the river mouth (31 km²) in 1930 to 124 km² in 1961 (Fig. 10).

*Hexagenia* nymphs were not collected in either 1930 or 1961 in an area from the mouth of the Detroit River southward along the Michigan shore to a point about 8 km south of the Raisin River (shaded area in Fig. 12). The environment in this section apparently was unfavorable to mayflies in both years. Substantial numbers of mayflies (over 150/m²) were collected in 1930, but none in 1961, at two stations (1D and 7D) near the lakeward margin of the area. Wood (1963) also found no mayflies in his 1951–1952 samples from the vicinity of our Stations 4D, 7D, 8L, and 9L.

The average number of midges/m² increased substantially in this section between 1930 and 1961, but the stations with the smallest numbers in 1961 also were in this area. The abundance of midges either remained the same or decreased at stations nearest the river mouth; but at other stations, numbers were large in 1961 where none were taken in 1930. It is not possible to characterize the changes in midge numbers in the area as a whole because of the extreme variability among stations. It is evident, however, that the number/m² was

TABLE 14. *Density (no./$m^2$) of bottom organisms in 1930 and 1961 in the open-lake area*

| Station number | Oligochaeta |  | *Hexagenia* |  | Tendipedidae |  | Sphaeriidae |  | Gastropoda |  |
|---|---|---|---|---|---|---|---|---|---|---|
|  | 1930 | 1961 | 1930 | 1961 | 1930 | 1961 | 1930 | 1961 | 1930 | 1961 |
| 1L | 0 | 1,418 | 94 | 4 | 0 | 662 | 162 | 675 | —* | 189 |
| 2L | 20 | 284 | 634 | 0 | —* | 72 | —* | 31 | —* | 4 |
| 3L | 7 | 1,876 | 564 | 0 | —* | 176 | —* | 2,524 | —* | 1,161 |
| 4L | 0 | 3,105 | 317 | 4 | 34 | 540 | 54 | 2,120 | 0 | 540 |
| 5L | 0 | 405 | 358 | 0 | 20 | 216 | 14 | 243 | 0 | 90 |
| 6L | 20 | 648 | 462 | 4 | 18 | 81 | 42 | 621 | 0 | 81 |
| 8L | 0 | 972 | 310 | 0 | 0 | 675 | 14 | 972 | 0 | 126 |
| 9L | 0 | 621 | 411 | 0 | —* | 432 | —* | 148 | —* | 54 |
| Mean number† | 6 | 1,166 | 394 | 1.5 | 14 | 435 | 57 | 926 | 0 | 209 |
| 1961 to 1930 ratio | 194.33:1 |  | 0.004:1 |  | 31.07:1 |  | 16.24:1 |  | — |  |

* No data.
† Based on stations with data available for both years.

reduced at stations in the western half of the section in 1961 (Fig. 3), and only *Procladius* was abundant at the stations with large counts of midge larvae (Table 3).

Increases were moderate in the number/$m^2$ of fingernail clams (ratio of 1.81) and gastropods (ratio 1.48) in 1961 (Table 13). In contrast to the Maumee River area, where midges and tubificids were the most numerous, the bottom fauna at most stations in the Detroit River section was dominated by fingernail clams and tubificids.

### *Open-lake area*

The bottom fauna of the open-lake area in 1930 included extremely small numbers of oligochaetes, midges, and gastropods; moderate numbers (average 57/$m^2$) of fingernail clams; and large numbers (average 394/$m^2$) of *Hexagenia* nymphs. In 1961 the bottom fauna of this section (Table 14) consisted of oligochaetes (average number more than 1,000/$m^2$), midges (up to 675/$m^2$), fingernail clams (average 926/$m^2$), and gastropods (average 209/$m^2$); mayfly nymphs averaged less than 2/$m^2$. The degree of change in all of the major taxonomic groups of bottom fauna in this area exceeded greatly that in the other three.

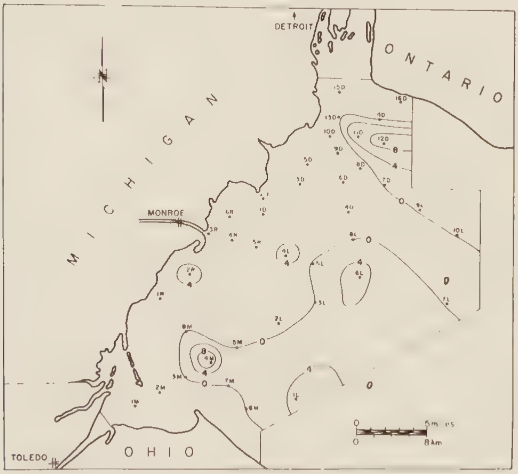

FIG. 13. Distribution of *Hexagenia* (no./$m^2$) in western Lake Erie, 1961.

The open-lake area was free of pollution in 1930, but in 1961 about half of it was moderately polluted, and the entire section (and perhaps all of the western basin) was lightly polluted (100–999 worms/$m^2$).

Mayfly nymphs were abundant in the open lake in 1930; the number/$m^2$ ranged from 94 to 634 and averaged 394 (Table 14). The distribution of mayflies in 1930 (Fig. 12) was similar to the distribution in 1961 of *Sphaerium corneum* (Fig. 6) and naiads (Fig. 9) and the reverse of the 1961 distribution of oligochaetes (Fig. 2). The drastic reduction in the mayfly population is illustrated by the similar location of the 400/$m^2$ isopleth for 1930 (Fig. 12) and the 0/$m^2$ isopleth for 1961 (Fig. 13).

The average number of midge larvae/$m^2$ (14) in the open lake was the lowest for the four areas in 1930 but was highest (435) in 1961 (Table 14). Numbers of fingernail clams also increased greatly and reached their highest values in this section; their average density was only slightly below that of the oligochaetes. Samples at four stations that had no snails in 1930 yielded an average of $209/m^2$ in 1961. The increases in numbers of oligochaetes, midges, fingernail clams, and snails in 1961 as compared to 1930 are apparently due to increased enrichment of the bottom sediments. The relatively large number of species collected in the area indicate the absence of gross pollution, but the depletion of mayflies (the only group for which environmental conditions apparently had become critical by 1961) indicates more severe environmental conditions in 1961 than in 1930.

## REFERENCES

Baker, F. C. 1928. The freshwater Mollusca of Wisconsin, Part 2, Pelecypoda. Wisconsin Geological and Natural History Survey, Bull. 70, Part 2. 495 p.

Beeton, A. M. 1961. Environmental changes in Lake Erie. Trans. Am. Fisheries Soc., **90:** 153–159.

———. 1965. Eutrophication of the St. Lawrence Great Lakes. Limnol. Oceanog., **10:** 240–254.

Bradshaw, A. S. 1964. The crustacean zooplankton picture: Lake Erie 1939–49–59; Cayuga 1910–51–61. Verhandl. Intern. Ver. Limnol., **15:** 700–708.

Britt, N. W. 1955*a*. Stratification in western Lake Erie in summer of 1953: effects on the *Hexagenia* (Ephemeroptera) population. Ecology, **36:** 239–244.

———. 1955*b*. *Hexagenia* (Ephemeroptera) population recovery in western Lake Erie following the 1953 catastrophe. Ecology, **36:** 520–522.

Brown, E. H., Jr. 1953. Survey of the bottom fauna at the mouths of ten Lake Erie, south shore rivers: its abundance, composition, and use as index of stream pollution. Ohio, Div. Water, Final Rept., Columbus, Ohio. 201 p.

Carr, J. F. 1962. Dissolved oxygen in Lake Erie, past and present. Great Lakes Res. Div., Inst. Sci. and Tech., Univ. Mich., Publ. No. 9, p. 1–14.

———, V. C. Applegate, and M. Keller. 1965. A recent occurrence of thermal stratification and low dissolved oxygen in western Lake Erie. Ohio J. Sci., in press.

Davis, C. C. 1964. Evidence for the eutrophication of Lake Erie from phytoplankton records. Limnol. Oceanog., **9:** 275–283.

Heard, W. H. 1962. The Sphaeriidae (Mollusca: Pelecypoda) of the North American Great Lakes. Am. Midland Naturalist, **67:** 194–198.

Hiltunen, J. K. 1965. Distribution and abundance of the polychaete, *Manayunkia speciosa* Leidy, in western Lake Erie. Ohio J. Sci., **65:** 183–185.

Hynes, H. B. N. 1960. The biology of polluted waters. Liverpool Univ. Press, Liverpool, England. 202 p.

Ingram, W. M. 1957. Use and value of biological indicators of pollution: freshwater clams and snails, p. 94–135. *In* C. M. Tarzwell [ed.], Biological problems in water pollution. U.S. Public Health Service.

International Joint Commission. 1951. Report of the International Joint Commission United States and Canada on the pollution of boundary waters. Washington and Ottawa. 312 p.

Surber, E. W. 1957. Biological criteria for the determination of lake pollution, p. 164–174. *In* C. M. Tarzwell [ed.], Biological problems in water pollution. U.S. Public Health Service.

Verduin, J. 1964. Changes in western Lake Erie during the period 1948–1962. Verhandl. Intern. Ver. Limnol., **15:** 639–644.

Whipple, G. C. 1948. The microscopy of drinking water. 4th ed., revised by G. M. Fair and M. C. Whipple. Wiley, New York. 586 p.

Wood, K. G. 1963. The bottom fauna of western Lake Erie, 1951–52. Great Lakes Res. Div., Inst. Sci. and Tech., Univ. Mich., Publ. No. 10, p. 258–265.

Wright, S. 1955. Limnological survey of western Lake Erie. U.S. Fish Wildlife Serv., Spec. Sci. Rept., Fisheries, **139:** 341 p.

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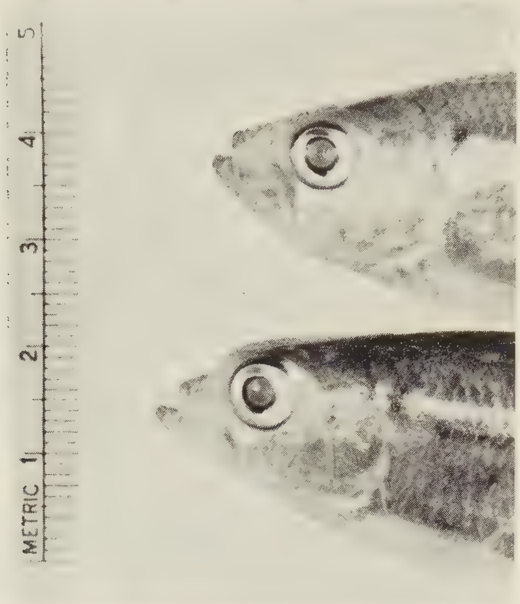

Figure 1.—Young-of-the-year American shad: normal, above; pugheaded below.

## Pugheadedness in an American Shad

Pugheadedness has been cited for several fish including brown trout, *Salmo trutta*; carp, *Cyprinus carpio*; a cod, *Gadus* sp.; white perch, *Roccus americanus*; striped bass, *Roccus saxatilis*; largemouth bass, *Micropterus salmoides*; yellow perch, *Perca flavescens*; a percid, *Stizostedion* sp.; and silver perch, *Bairdiella chrysura* (Gudger, 1930; Mansueti, 1958). This anomaly is due to an upraising of the median portion of the cranium. According to Gudger (1930), "The anterior ends of the frontals have been bent almost vertically downward, the parasphenoid has been buckled up almost vertically, and the nasals, ethmoid, and vomer have been bent backward, inward, and upward until they have come to fill quite half of the orbital cavity." Environment and heredity are probable causes of pugheadedness; mechanical injury has been discounted (Mansueti, 1960).

On 25 October 1963, a pugheaded American shad, *Alosa sapidissima* (Wilson), was collected in the Cape Fear River, North Carolina, at river mile 47 (Figure 1). The head in the region of the eyes has been upraised and the top of the head is nearly horizontal but the outline of the lower jaw is normal. The forehead is steep and the upper jaw appears to be lacking. There is an apparent increase in the interorbital width, but no exophthalmia.

This specimen measured 95 mm fork length and was taken in a sample of 25 young-of-the-year American shad ranging from 94 to 115 mm. The mean fork length of the fish in the sample was 107 mm. As far as the author knows, this is the first report of pugheadedness in American shad. The specimen collected in the Cape Fear River is in the United States National Museum with Catalog Number USNM 197795.

### LITERATURE CITED

GUDGER, E. W. 1930. Pugheadedness in the striped sea bass, *Roccus lineatus*, and in other related fishes. Bull. Amer. Mus. Nat. Hist., 61(1): 1–19.

MANSUETI, ROMEO J. 1958. Eggs, larvae, and young of the striped bass, *Roccus saxatilis*. Maryland Dept. Res. and Educ., Contrib. 112: 1–35.

———. 1960. An unusually large pugheaded striped bass, *Roccus saxatilis*, from Chesapeake Bay, Maryland. Chesapeake Sci., 1(2): 111–113.

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# SELF-CLOSING DEVICE FOR SAMPLING PLANKTON NEAR THE SEA BOTTOM

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# SELF-CLOSING DEVICE FOR SAMPLING PLANKTON NEAR THE SEA BOTTOM[1]

The apparatus described here was designed to obtain samples of plankton from near the sea floor. It can be used from a small boat operating over a smooth bottom in shallow water.

Other apparatus designed for collecting plankton in the immediate vicinity of the bottom (Russell 1928; Bossanyi 1951; Wickstead 1953) and conventional conical nets (Sverdrup, Johnson, and Fleming 1942) have inadequate closing mechanisms or are

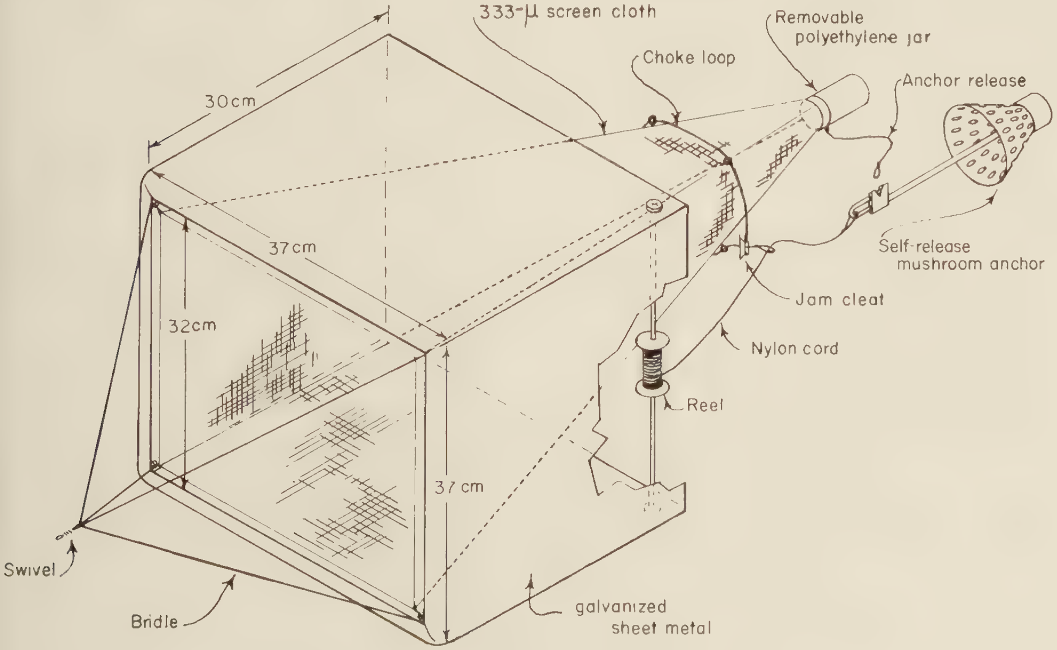
30 cm
333-μ screen cloth
Removable polyethylene jar
Choke loop
Anchor release
37 cm
32cm
Self-release mushroom anchor
Jam cleat
Nylon cord
Reel
37 cm
Swivel
Bridle
galvanized sheet metal

FIG. 1. Diagram of self-closing bottom plankton net.

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[1] This device was developed during an ecological study supported in part by National Science Foundation Grant G-7141 to Dr. E. W. Fager of Scripps Institution of Oceanography, and in part by Scripps Tuna Oceanography Research of Scripps Institution of Oceanography with funds provided by U.S. Bureau of Commercial Fisheries under Contract 14-17-0007-28.

too cumbersome to be efficiently handled from a small boat. Continuous collection devices (Hardy 1936; Glover 1953) and plankton pumps (Aron 1958) are impractical because they must have rather small mouth openings.

A dredge, combining a plankton net with continuous evacuation of the cod end by a pumping system (Tonolli 1958), capable of simultaneously metering distance and monitoring *in situ* temperature, was constructed and tested. Although the technical operation of this collection system was reasonably successful, underwater observations of its operation showed that smaller zooplankton were often forced against the sides of the net near the cod end and held there. Larger zooplankton such as mysids could maintain their position within the net just ahead of the cod end for many seconds. This mixing defeated the purpose of the device, which was to collect animals in the order of their actual position along a transect line.

The model of the self-closing device (Figs. 1 and 2) has a mouth area of 1,000 cm$^2$ and a filtering surface of 4,600 cm$^2$ of 333-$\mu$ monofilament nylon screen cloth. Since the open area in the net mesh is 48% of the net area, the ratio of open area in the net to the mouth area is 2.2 to 1. The net is fixed within an open-ended galvanized sheet metal (0.9-mm or 0.035-inch thick) box which has curved leading edges and is weighted inside with about 9 kg (20 lb) of sheet lead.

In operation, the instrument is lowered vertically, cod end first, with a winch and boom (Fig. 2). Upon reaching the bottom, the base of the self-release anchor (below the perforated cone) forces the attached inner rod upward through the tubular anchor shaft. This disengages the anchor (weight about 3 kg) from the cod end of the net. When towing begins, the weighted box is pulled over onto any one of its four sides and the anchor remains in its original position. At the end of the traverse, a ring catch near the net end of the nylon anchor line pulls the choke loop (flexible plastic-coated steel wire) closed; the choke loop is held closed by a one-way jam cleat (Fig.

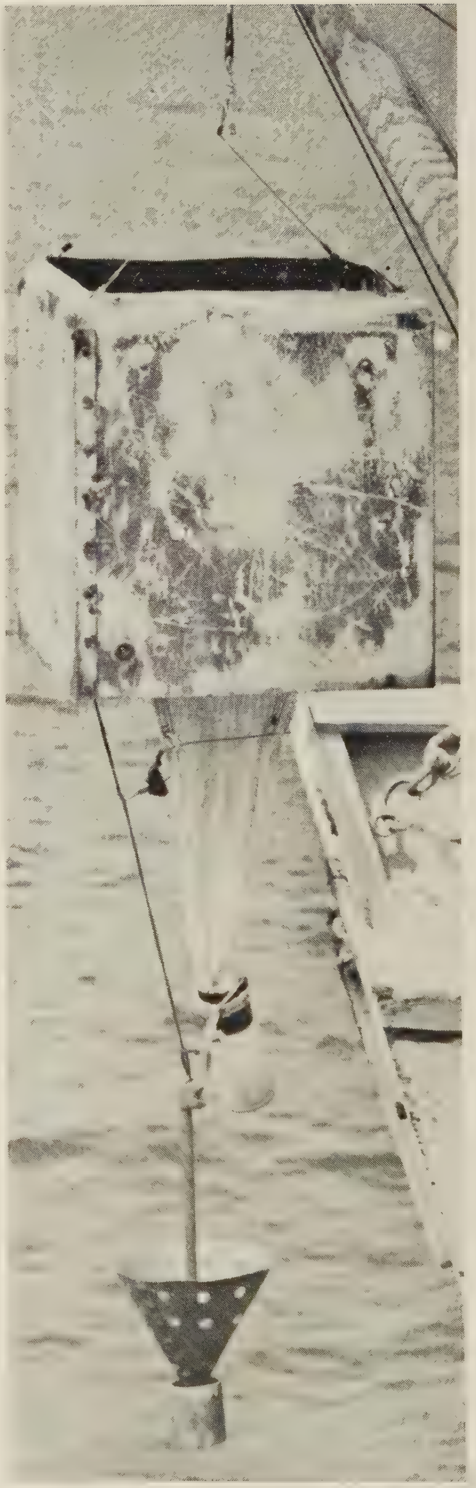

FIG. 2. Self-closing bottom plankton net in lowering position.

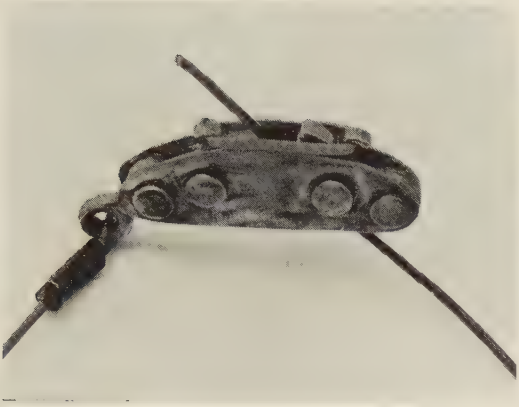

FIG. 3. One-way jam cleat.

3). The net is recovered with the winch prior to recovery of the self-release anchor. Perforations in the mushroom anchor facilitate its recovery.

This device was usually used for hauls 10 m long, and towing speed of 80 to 100 cm/sec (1.6–1.9 knots). Two years of use showed that it could be easily handled under varied sea conditions, often near the surf, by one man operating a skiff with an outboard engine. Underwater observations of the device showed that its mechanical performance was satisfactory, and that, once taken in the net, the animals were retained. Detailed flow measurement tests made at a velocity of 100 cm/sec demonstrated that the filtering efficiency was about 68%, and that the velocity of water entering the net was essentially the same at all places in the mouth cross-section. Repeated sampling of an unchanging zooplankton population yielded consistent catches, although the true catching efficiency, as affected by avoidance, was not determined.

A larger model of this device (Fig. 4) was made by affixing a standard meter-net (specifications given by Ahlstrom 1948) within a similar metal housing constructed of 0.9 mm (0.035 inch) sheet metal riveted to a framework of 6.4 mm × 58 mm (¼ inch × 2 inch) steel. This model has a mouth area of 5,000 cm$^2$ and a total straining surface of 74,800 cm$^2$ of 333-$\mu$mesh, giving a ratio of open area in the net to mouth area of 7.2 to 1. Filtering efficiency of this large net is more than 80% at a tow rate of 100 cm/sec.

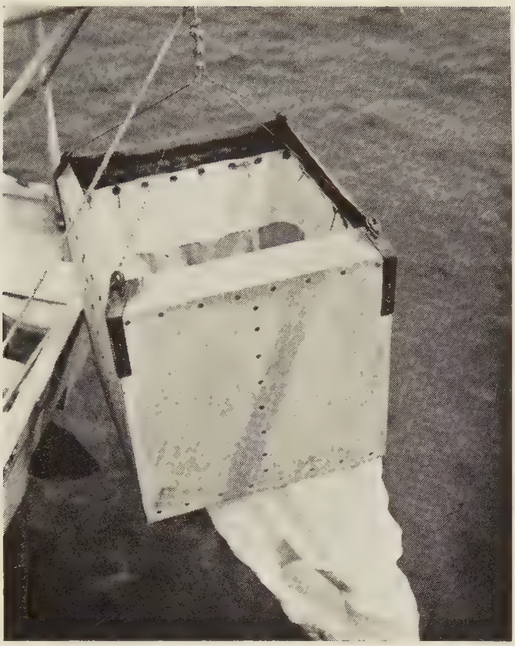

FIG. 4. Meter-net bottom plankton sampler.

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## REFERENCES

AHLSTROM, E. H. 1948. A record of pilchard eggs and larvae collected during surveys made in 1939 to 1941. U.S. Fish Wildlife Serv., Spec. Sci. Rept., **54**: 8–9.

ARON, W. 1958. The use of a large capacity portable pump for plankton sampling, with notes on plankton patchiness. J. Marine Res., **16**: 158–173.

BOSSANYI, J. 1951. An apparatus for the collection of plankton in the immediate vicinity of the sea bottom. J. Marine Biol. Assoc. U.K., **30**: 265–270.

GLOVER, R. S. 1953. The Hardy plankton indicator and sampler: a description of various models in use. Hull Bull. Marine Ecol., **4**: 7–20.

HARDY, A. C. 1936. The continuous plankton recorder. Discovery Rept., **11**: 457–510.

RUSSELL, F. S. 1928. A net for catching plankton near the bottom. J. Marine Biol. Assoc. U.K., **15**: 105–108.

SVERDRUP, H. U., M. W. JOHNSON, AND R. H. FLEMING. 1942. The oceans. Prentice-Hall, Englewood Cliffs, N.J. 1087 p.

TONOLLI, V. 1958. Ricerche sulla microstruttura di distribuzione dello zooplancton nel Laggo Maggiori. Mem. Ist. Ital. Idrobiol. Marchi, **10:** 125–152.

WICKSTEAD, J. 1953. A new apparatus for the collection of bottom plankton. J. Marine Biol. Assoc. U.K., **32:** 347–355.

## ATLANTIDE REPORT No. 8

*Scientific Results of the Danish Expedition to the Coasts of Tropical West Africa*
*1945–1946*

# Hemiramphidae (Pisces, Synentognathi) from Tropical West Africa

*by*

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Bauchot, M. L. & M. Blanc: Poissons marins de l'Est Atlantique Tropical. I. Labroidei (Téléostéens Perciformes).
Bauchot, M. L. & M. Blanc: Poissons marins de l'Est Atlantique Tropical. II. Percoidei (Téléostéens Perciformes). 1ère partie.
Nielsen, Jørgen: Psettodoidea and Pleuronectoidea (Pisces, Heterosomata).
Tendeiro, João: Une nouvelle espèce de mallophage *Mulcticola wolffi* n. sp. (Ischnocera, Philopteridae) parasite de *Caprimulgus inornatus* Heuglin.
Clay, Theresa: Mallophaga (Insecta) from West African Birds.
Gaud, J.: Acarina-Analgesoidea parasites des oiseaux de l'Afrique Occidentale.
Tattersall, Olive S.: Mysidacea from the Coasts of Tropical West Africa.
Chuang, S. H.: Description of *Lingula parva* Smith (Brachiopoda) from the Coast of Tropical West Africa.
Nørvang, Aksel: Schizamminidae, a New Family of Foraminifera.
Forest, Jacques: Pagurides de l'Afrique occidentale.
Boden, Brian P.: Euphausiacea (Crustacea) from Tropical West Africa.

Price: 55 Danish Kr. (= about 8 U.S.$)

(Continued on p. 3 of the cover)

# Hemiramphidae (Pisces, Synentognathi) from Tropical West Africa*

*by*

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(BUREAU OF COMMERCIAL FISHERIES ICHTHYOLOGICAL LABORATORY,

U.S. NATIONAL MUSEUM, WASHINGTON, D. C.)

Most of the material treated in this paper was collected by the "Atlantide" Expedition (1945–46) along the coast of West Africa from the Canary Islands to Angola (BRUUN, 1950) and by the "Galathea" Expedition (1950) off West Africa at depths less than 400 m (BRUUN, 1959; WOLFF, 1964). Another large segment of material was collected by the author on board the "La Rafale" during Guinean Trawling Survey I (WILLIAMS, 1964). These GTS specimens are now catalogued in the U.S. National Museum. Additional material has been examined from the following museums:

| | |
|---|---|
| USNM: | U.S. National Museum, Washington, D.C. |
| BMNH: | British Museum (Natural History), London. |
| MNHN: | Muséum National d'Histoire Naturelle, Paris. |
| MRCB: | Musée Royal Congo Belge, Teruven, Belgium. |
| SFRS: | Sea Fisheries Research Station, Haifa, Israel. |
| CU: | Cornell University, Ithaca, New York. |
| CNHM: | Chicago Natural History Museum, Chicago, Illinois. |
| SU: | Stanford University, Division of Systematic Biology, Stanford, California. |
| MCZ: | Museum of Comparative Zoology, Harvard University, Cambridge, Massachusetts. |

The present material comprises 837 specimens belonging to the four species of Hemiramphidae found off West Africa. *Hyporhamphus picarti* from the Mediterranean Sea is dealt with in this study, but species of Hemiramphidae that reportedly have recently invaded the eastern Mediterranean Sea from the Red Sea (TORTONESE, 1952; BEN-TUVIA, 1953; FOWLER and STEINITZ, 1956) are not considered. Comparisons between western and eastern Atlantic specimens of both species of *Hemiramphus* are made. This paper is my second in a series of systematic studies on synentognaths (COLLETTE, 1962).

The following abbrevations are used (all measurements in mm):

| | |
|---|---|
| SL | Standard length, from tip of upper jaw to caudal base. |
| D | Dorsal fin rays. All elements counted. |

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* Guinean Trawling Survey Contribution No. 2.

| | |
|---|---|
| A | Anal fin rays. All elements counted. |
| $P_1$ | Pectoral fin rays. All elements counted. |
| $GR_1$ | Gill rakers on first arch (total on right side). |
| $GR_2$ | Gill rakers on second arch (total on right side). |
| LJL | Lower jaw length, distance from tip of upper jaw to tip of lower jaw. |
| $P_1L$ | Pectoral fin length, distance from base of uppermost pectoral ray to tip of longest ray. |
| $P_1$–$P_2$ | Distance from base of uppermost pectoral ray to base of anteriormost pelvic ray. |
| $P_2$–C | Distance from base of anteriormost pelvic ray to caudal base.<br>Also expressed as $P_2$–C extension, which is this distance extended anteriorly from base of anteriormost pelvic ray. |

I thank the following for making material available: Jørgen G. Nielsen (Copenhagen); Frank G. Williams (GTS); P. H. Greenwood (BMNH); M. L. Bauchot (MNHN); Max Poll (MRCB); Adam Ben-Tuvia (SFRS); Edward C. Raney (CU); Loren P. Woods (CNHM); George S. Myers (SU); and Giles W. Mead (MCZ). The drawings were done by Mildred H. Carrington. Robert E. Jenkins and Harold Lazard took radiographs and assisted with the preparation of the maps, tables, and graphs. The manuscript was read and criticized by Frederick H. Berry, Daniel M. Cohen, John E. Fitch, and Robert H. Gibbs, Jr.

## KEY TO HEMIRAMPHIDAE OF WEST AFRICA

1. D 21–24; A 20–24; $P_1$ 7–7 1/2 .......................... *Euleptorhamphus velox*
   D 12–16; A 10–18; $P_1$ 9–12 .......................... 2
2. Caudal fin slightly forked (Fig. 7); scales present on snout; preorbital ridge well developed; A usually 14–17 .......................... *Hyporhamphus picarti*
   Caudal fin deeply forked, lower lobe much longer than upper lobe (Fig. 3); no scales on snout; preorbital ridge absent; A usually 10–13 .......... *Hemiramphus* ...... 3
3. Pectoral fin long (Fig. 1), its length greater than distance from base of uppermost pectoral ray to anterior margin of nasal fossa; A usually 11 or 12; upper caudal lobe of adults bluish-violet in life .......................... *H. balao*
   Pectoral fin short (Fig. 1), its length less than distance from base of uppermost pectoral ray to anterior margin of nasal fossa; A usually 12 or 13; upper caudal lobe of adults reddish – orange in life .......................... *H. brasiliensis*

### **Euleptorhamphus velox** Poey

(Fig. 2)

*Euleptorhamphus velox* Poey, 1868: 383 (original description: Cuba).

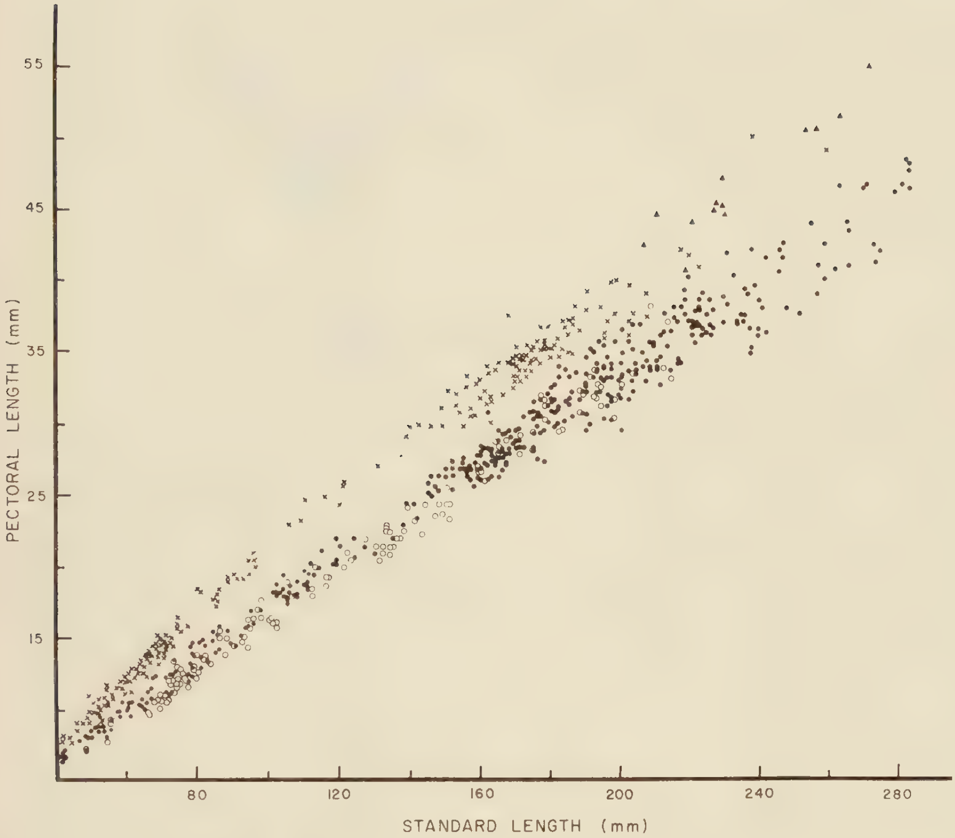

Fig. 1. Pectoral fin length in *Hemiramphus*. ● western Atlantic, ○ eastern Atlantic *H. brasiliensis*. × western Atlantic, ▲ eastern Atlantic *H. balao*.

**Material:**

USNM 188746: south of Lagos, Nigeria. IV: 19:63,—1 (118).

Diagnosis: *E. velox* is very closely related to *E. viridis* (van Hasselt) and differs mainly in having either 7 pectoral rays or 7 plus a tiny splint whereas *E. viridis* has 8 or 8 plus a tiny splint. *E. velox* averages about one dorsal and one anal ray less than *E. viridis* and has slightly more gill rakers.

Holotype: MCZ 8779, 248 mm SL, Cuba, Poey no. 422. D 22; A 22; $P_1$ 7 1/2–7 1/2; $RGR_1$ 6+22 = 28; LJL 96.5 mm; $P_1L$ 61.1 mm.

Distribution: Atlantic Ocean, in the western Atlantic from Newport, Rhode Island, south through the Gulf of Mexico and Caribbean Sea to Recife, Brazil (Collette, MS). In the eastern Atlantic, known from the Cape Verde Islands (Cadenat, 1949, 1950), off Sierre Leone (8 42′N, 17 11′W, Parin, 1964), and the present record from Nigeria. Also reported from Walfish Bay, South Africa (Barnard, 1925).

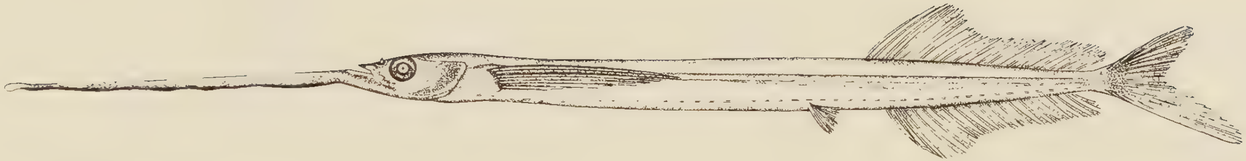

Fig. 2. *Euleptorhamphus velox* Poey. USNM 188747. "Silver Bay" St. 2201. 34°34′N, 75°40′W. 135 mm. SL.

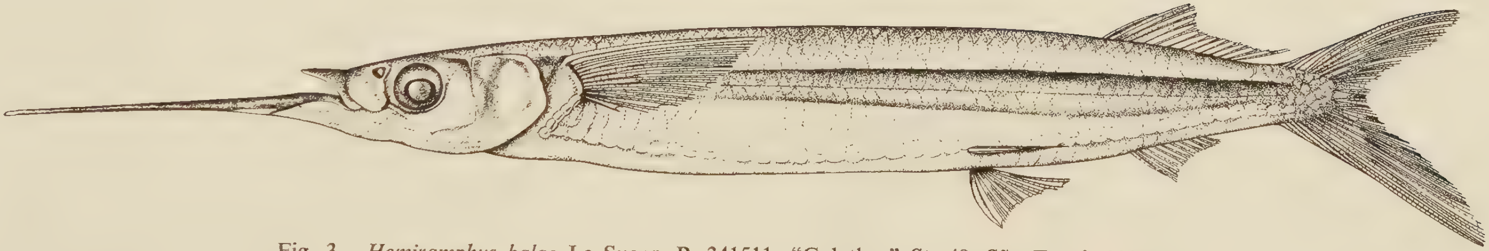

Fig. 3. *Hemiramphus balao* Le Sueur. P. 341511. "Galathea" St. 49. São Tomé. 220 mm. SL.

Discussion: PARIN (1964) considered *E. velox* to be no more than an Atlantic subspecies of the Indo-Pacific *E. viridis*. There is an almost complete separation based on number of major pectoral rays, and by plotting dorsal versus anal rays, specimen by specimen, I can show a 75% separation of Atlantic from Indo-Pacific specimens. Therefore, I retain *E. velox* as a separate species, at least until my revisionary studies are more complete.

### **Hemiramphus balao** Le Sueur

(Fig. 3).

*Hemiramphus balao* Le Sueur, 1823: 136 (original description; Guadeloupe and Martinique, Lesser Antilles).

*Hemiramphus vittatus* Valenciennes, 1843: 70 (original description; Lancerote and Arecife, Canary Islands).

*Hemiramphus Pleii* Valenciennes *in* Cuvier and Valenciennes, 1846: 21 (original description; Cuba, Martinique).

*Hemirhamphus macrochirus* Poey, 1860: 299 (original description; Cuba).

*Hemiramphus guineënsis* Bleeker, 1863: 119 (original description; Annoukor, Boutry, Guinea), pl. 25, fig. 2.

**Material:**

14 specimens (206–284 mm. SL) from 9 collections.

"Atlantide" St. 117, off Victoria, Cameroons. P 341996–97. II: 24:46, -- 2 (226–228).

"Galathea" St. 49, Isle of Rolas, São Tomé, 0°00′, 6°32′E. P. 341511. XI:29:50, -- 1 (220).

"Eclipse" USNM 42273–4–5–7, Luanda, Angola. XII:10:89, -- 4 (252–270).

"Calypso" St. 76. MNHN 57–95, Gulf of Guinea. VII:58,--2 (210–227).

"Expédition Oceánographique Belge" St. 51. MRCB 95506, 6°18′S, 33°33′E. X:25:48,--1 (229).

MRCB: 74704, Luanda, Angola. VII:49,--1 (206).

BMNH: 1847.4.4.25, Niger Expedition,--1 (218).
1963.10.18.1, West Africa, probably Ghana,--1 (228).

MNHN: B. 2183, Canary Islands,--1 (284).

Diagnosis: A species of *Hemiramphus* with a moderate number of gill rakers, usually 32–37 on the first arch and 26–30 on the second arch (Table 1); a low number of anal rays, usually 11 or 12 (Table 2); a long pectoral fin (Fig. 1), its length greater than the distance from the base of the uppermost pectoral ray to the anterior margin of the nasal fossa; 54–56 vertebrae, 37–40 precaudal, and 15–17 caudal; adults with a bluish-violet upper caudal lobe in life; juveniles with the tip of the lower caudal lobe unpigmented and the pelvic fin pigmentation concentrated proximally.

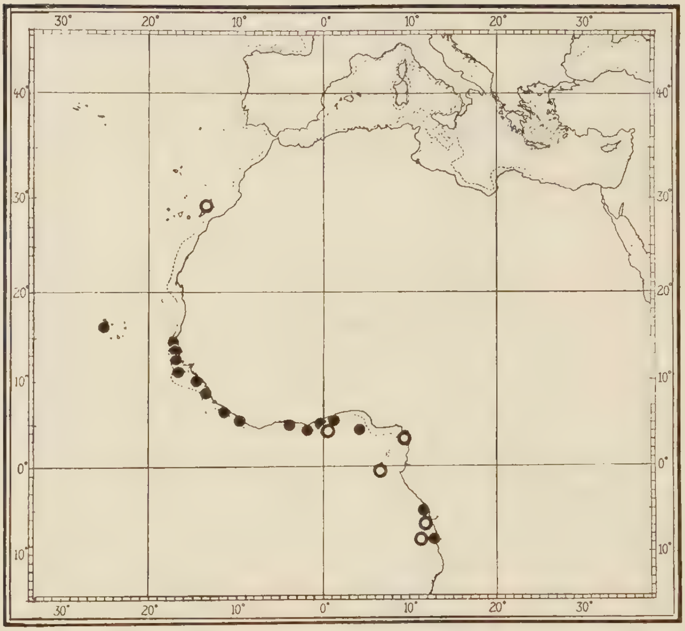

Fig. 4. Distribution of *Hemiramphus* in the eastern Atlantic based on specimens examined. ● *H. brasiliensis.* ○ *H. balao.*

Table 1. Number of gill rakers in eastern and western Atlantic *Hemiramphus balao* and *H. brasiliensis.*

| | First arch | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 28 | 29 | 30 | 31 | 32 | 33 | 34 | 35 | 36 | 37 | 38 | 39 | N | x̄ |
| *H. brasiliensis* | | | | | | | | | | | | | | |
| w. Atlantic | 2 | 24 | 70 | 101 | 59 | 37 | 9 | 3 | 1 | – | – | – | 306 | 31.17 |
| e. Atlantic | 1 | 3 | 12 | 19 | 48 | 37 | 27 | 19 | 7 | 1 | 2 | – | 176 | 32.78 |
| *H. balao* | | | | | | | | | | | | | | |
| w. Atlantic | – | – | – | 1 | 14 | 20 | 20 | 34 | 20 | 10 | – | – | 119 | 34.45 |
| e. Atlantic | – | – | – | – | – | – | – | 1 | 1 | 6 | 2 | 1 | 11 | 37.09 |

| | Second arch | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 20 | 21 | 22 | 23 | 24 | 25 | 26 | 27 | 28 | 29 | 30 | N | x̄ |
| *H. brasiliensis* | | | | | | | | | | | | | |
| w. Atlantic | 1 | 4 | 10 | 34 | 52 | 54 | 34 | 3 | 1 | 1 | – | 194 | 24.36 |
| e. Atlantic | – | – | 3 | 3 | 16 | 40 | 50 | 31 | 12 | 3 | 2 | 160 | 25.87 |
| *H. balao* | | | | | | | | | | | | | |
| w. Atlantic | – | – | – | – | – | 2 | 5 | 12 | 8 | 2 | 1 | 30 | 27.20 |
| e. Atlantic | – | – | – | – | – | – | – | 1 | 3 | 3 | 4 | 11 | 28.91 |

TABLE 2. Number of fin rays in eastern and western Atlantic *Hemiramphus balao* and *H. brasiliensis.*

| | Dorsal rays | | | | | | |
|---|---|---|---|---|---|---|---|
| | 11 | 12 | 13 | 14 | 15 | N | x̄ |
| *H. brasiliensis* | | | | | | | |
| w. Atlantic.......... | – | 2 | 118 | 254 | 15 | 389 | 13,72 |
| e. Atlantic.......... | – | 1 | 48 | 124 | 8 | 181 | 13.77 |
| *H. balao* | | | | | | | |
| w. Atlantic.......... | 1 | 4 | 112 | 102 | 1 | 220 | 13.45 |
| e. Atlantic.......... | – | – | 9 | 3 | – | 12 | 13.25 |

| | Anal rays | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | 10 | 11 | 12 | 13 | 14 | 15 | N | x̄ |
| *H. brasiliensis* | | | | | | | | |
| w. Atlantic.......... | – | 1 | 115 | 292 | 11 | 1 | 420 | 12.75 |
| e. Atlantic.......... | – | – | 21 | 136 | 24 | – | 181 | 13.02 |
| *H. balao* | | | | | | | | |
| w. Atlantic.......... | 3 | 104 | 140 | 5 | – | – | 252 | 11.58 |
| e. Atlantic.......... | 2 | 6 | 4 | – | – | – | 12 | 11.17 |

Types of Nominal Species: *Hemiramphus balao* Le Sueur. Types apparently not extant.

*Hemiramphus vittatus* Valenciennes. Holotype MNHN B. 2183, 284 mm SL, halt a skin mounted on a board. Found in the Paris collections in October, 1963 labeled as *Hemiramphus Browni*, Canaries, Webb and Berthelot. Its total length is about 402 mm, reasonably close to VALENCIENNES' "$0^{m}$, 41." D 14; A 10; LJL 70.2+ mm; $P_1L$ about 47 mm.

*Hemiramphus pleii* Valenciennes. Lecotype MNHN B. 1050, 180 mm SL, Martinique, herein selected. D 13; A 11; $RGR_1$ 9+25 = 34; and $P_1L$ 35.7 mm. VALENCIENNES based his description upon two specimens collected by DESMAREST in Cuba (MNHN B. 1048 and B. 1051), and two from Martinique, one collected by ACHARD (MNHN B. 1049) and one by CHORIS (MNHN B. 1050). The latter specimen best typifies *H. balao* and so is designated lectotype. The other specimen from Martinique is a specimens of *H. brasiliensis*. Both Cuban specimens fit VALENCIENNES' description adequately, represent *H. balao*, and so are considered as paralectotypes.

*Hemirhamphus macrochirus* Poey. Lectotype: MCZ 693, 186 mm SL, Cuba, Poey original no. 199, herein selected. D 13; A 12; $RGR_1$ 9+25 = 34; $P_1L$ 37.5 mm. The original description and this specimen clearly represent *H. balao*. USNM 4748 was labeled as a type of *H. macrochirus*, but it is a specimen of *H. brasiliensis*.

*Hemiramphus guineensis* Bleeker. Types not examined.

Distribution: Atlantic Ocean, in the western Atlantic from off New York south throughout the Gulf of Mexico and the Caribbean Sea to Santos, Brazil

(Collette, 1962), and in the eastern Atlantic from the Canary Islands south to Luanda, Angola (Fig. 4).

Discussion: Previous authors (Fowler, 1919, 1936, and Poll, 1953) have considered all the nominal species of *Hemiramphus* from West Africa referable to *H. brasiliensis*. Fowler (1919: 277) pointed out that his Angola specimens fell into two groups, one with longer pectorals and fewer anal rays (USNM 42273–4–5–7) than the other (USNM 42276–8). He failed to recognize that he had two species in the series, and examined additional material from Puerto Rico, New Jersey, Chesapeake Bay, and Hawaii which led him to the conclusion that all the specimens [of three species] were *H. brasiliensis*.

The eastern Atlantic population of *H. balao* has a higher number of gill rakers, especially on the first arch, than the western Atlantic population (Table 1); however, dorsal and anal fin ray counts are similar on opposite sides of the Atlantic (Table 2).

It is difficult to compare body proportions of eastern with western Atlantic *H. balao*, because only large adults are available from the eastern Atlantic. These large eastern Atlantic specimens resemble western Atlantic specimens in the characters studied. Graphs for pectoral length (Fig. 1) and lower jaw length (Fig. 5) are the only comparisons presented here. No explanation can now be offered for the capture of only large specimens in the eastern Atlantic.

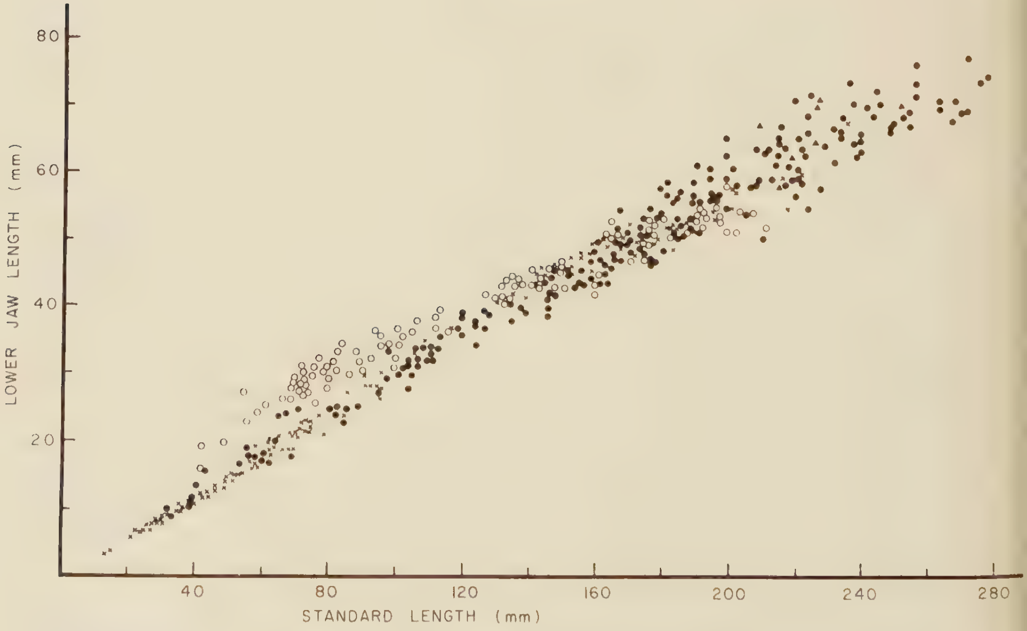

Fig. 5. Lower jaw length in *Hemiramphus*. ● western Atlantic, ○ eastern Atlantic *H. brasiliensis*. × western Atlantic, ▲ eastern Atlantic *H. balao*.

## **Hemiramphus brasiliensis** (Linnaeus)

(Fig. 6).

*Esox brasiliensis* Linnaeus, 1758: 314 (original description after Browne; Jamaica).
*Hemiramphus Brownii* Valenciennes *in* Cuvier and Valenciennes, 1846: 13 (original description; Martinique, Guadaloupe, Rio de Janeiro, Gorée).
*Hemirhamphus filamentosus* Poey, 1860: 297 (original description; Cuba).

### Material:

221 specimens (17–223 mm. SL) from 33 collections.

"Atlantide": St. 36, Porto Grande, St. Vincent, Cape Verde Islands. P. 341509. XII:8:45,--1 (212).
St. 52, off Monrovia, Liberia. P 341820–48. I:2:46,--29 (31–102).
St. 53, off Port Marshall, Liberia. P 341870–99. I:4–7:46,-- 30 (55–101).
St. 69, off Port Bouet, Côte d'Ivoire. P 341909–14. I:14:46,--6 (112–123).
St. 71, Takoradi, Ghana. P 341915. I:17–21:46,--1 (102).
St. 77, off Accra, Ghana. P 341933–6. I:24–29:46,--4 (89–175).
St. 104, 4°30′N, 5°23′E. P 341991. II:17:46,--1 (82).
St. 137, Luanda, Angola. USNM 188750. III:18–22:46,--17 (67–113).
St. 155, Bathurst, Gambia. P 342289–92. IV:18–24:46,--4 (176–192).

"Guinean Trawling Survey":
USNM 194424. BBC 862, 5°47′N, 10°18′W. XI:5:63,--1 (53).
194228. BBC 883, 6°18–42′N, 10°49′–11°22′W. XI:10:63,--29 (107–204).
194421. BBC 920–921, Freetown, Sierra Leone. XI:21–22:63,--29 (22–208).
194426. BBC 926, 8°34′N, 14°14′W. XI:24:63,--1 (23).
194425. BBC 949, 10°05′N, 14°41′W. XI:29:63,--7 (17–36).
194429. BBC 959, Freetown, Sierra Leone. XII:2:63,--4 (150–192).
194423. BBC 977, 10°44′–11°46′N, 17°06′–16°58′W. XII:8:63,--1 (100).
194422. BBC 992, 12°08′N, 17°14′W. XII:11:63,--2 (161–165).
194427. BBC 993, 12°08′N, 17°14′W. XII:12:63,--5 (25–33).

"Galathea": St. 10, Dakar, Senegal. P 34190–94. XI:6:50,--5 (49–160).

"Expédition Océanographique Belge":
St. 168. MRCB 95507–9, 4°55′S, 11°43′E. III:29:49,--3 (42–97).
St. 181. MRCB 95510–13, 8°31′S, 13°01′E. IV:11:49,--4 (105–166).
St. 188. MRCB 95514, 5°26′S, 11°40′E. V:3:49,--1 (69).

"Eclipse": USNM 42276, 42278, Luanda, Angola. XII:10:89,--2 (214–223).

"Crawford": USNM 198099, Luanda, Angola. III:11:57,--11 (55–101).

"Sylvana": St. 87, MNHN 41–16, Cape Verde Islands,--2 (164–167).

BMNH: 1930.8.26.18, Accra, Ghana,--1 (189).
1939.7.17.8, Keta, Ghana,--1 (175).

| | |
|---|---|
| CU: | Uncat., Ghana. VII:22:60,--2 (136–144). |
| | Uncat., Keta, Ghana. XII:30:59,--2 (42–74). |
| MNHN: | B. 1052, Gorée, Senegal,--3 (194–201). |
| USNM: | 193460–2, Liberia. XII:52,--10 (149–181). |
| SU: | 15858, Winnebah, Ghana. I:31:40,--1 (178). |
| MRCB: | 74705, Luanda, Angola,--1 (202). |

Diagnosis: A species of *Hemiramphus* with a low number of gill rakers, usually 29–35 on the first arch and 22–27 on the second arch (Table 1, p. 222–223); a high number of anal rays, usually 12 or 13 (Table 2); a short pectoral fin (Fig. 1), its length less than the distance from the base of the uppermost pectoral ray to the posterior margin of the nasal fossa; 52–55 vertebrae, 34–37 precaudal, and 16–18 caudal; adults with a reddish-orange upper caudal lobe in life; juveniles with the tip of the lower caudal lobe pigmented and the pelvic fin pigmentation concentrated distally.

Types of Nominal Species: *Esox brasiliensis* Linnaeus. Apparently no types extant.

*Hemiramphus brownii* Valenciennes. Lectotype MNHN 4585, 195 mm. SL, Martinique, Plée, 1826; herein selected. Valenciennes based his description on a specimen collected in Martinique by Plée. There are three syntypes of *H. brownii* in the MNHN from Martinique but one of them (4344) is a specimen of *H. balao*. A second (A. 7062) lacks the gill rakers which are one of the diagnostic characters. Therefore, the third specimen (4585) is selected as lectotype. It has D 13; A 12; $RGR_1$ $10+23 = 33$; and $P_1L$ 33.7 mm. Of Valenciennes' other original material extant paralectotypes are MNHN A. 7062 (1, 249), Martinique and MNHN B. 1052 (3, 194–201) Gorée, Senegal. Another paralectotype, MNHN B. 1053, Guadaloupe, is supposed to be mounted on a board but it could not be found in October 1963.

*Hemirhamphus filamentosus* Poey. Lectotype MCZ 8775, 237 mm SL, Poey original no. 50, Cuba, herein selected. D 14; A 13; $RGR_1$ $7+22 = 29$; $P_1L$ 35.5+mm. Paralectotypes MCZ 43030 (2, 195–225), removed from MCZ 8775. USNM 4746 (1, 182) was labeled as a type of *H. filamentosus* but is a specimen of *H. balao*.

Distribution: Atlantic Ocean; in the western Atlantic, from Woods Hole, Massachusetts south through the Gulf of Mexico and Caribbean Sea to Rio de Janeiro (Collette, 1962); in the eastern Atlantic, from the Cape Verde Islands and Dakar south to Luanda, Angola (Fig. 4). Replaced at Bermuda by *H. bermudensis*.

Discussion: Eastern Atlantic specimens have a slightly higher number of gill rakers on the first and second arches than western Atlantic individuals (Table 1, p. 222–223). The means for dorsal and anal ray counts are slightly higher in the eastern Atlantic (Table 2). The pectoral fin length is ismilar in eastern and western Atlantic specimens (Fig. 1). The lower jaw is longer in small specimens (40–120 mm SL) from the eastern Atlantic, but about the same in specimens in the middle size range (120–200 mm SL) (Fig. 5). The lower jaw probably is relatively shorter in large specimens (over 220 mm SL) from the eastern Atlantic.

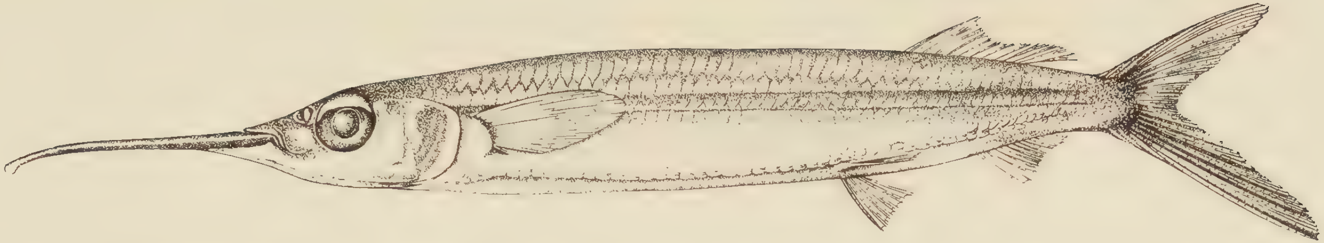

Fig. 6. *Hemiramphus brasiliensis* (Linnaeus). USNM 188749. "Gill" cruise 8. Settlement Point, Grand Bahamas. 119 mm. SL.

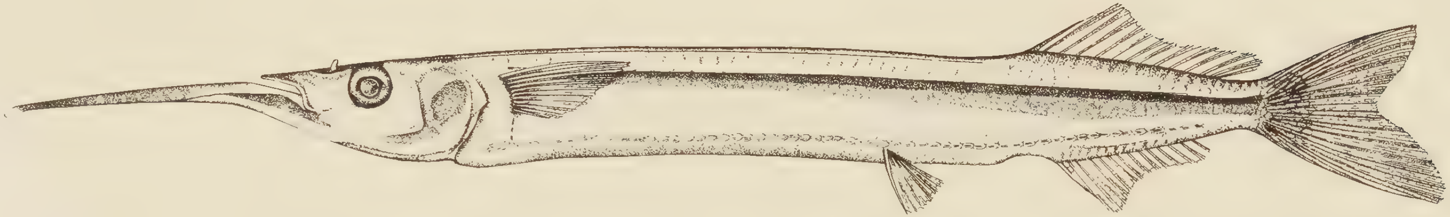

Fig. 7. *Hyporhamphus picarti* (Valenciennes). P. 341501. "Galathea" St. 36. Accra, Ghana. 120 mm. SL.

### **Hyporhamphus picarti** (Valenciennes)

(Fig. 7).

*Hemiramphus Picarti* Valenciennes *in* Cuvier and Valenciennes, 1846: 25 (original description; Bône, Algeria).
*Hemiramphus Schlegeli* Bleeker, 1863: 120 (original description; Ghana), pl. 25, fig. 1.
*Hemirhamphus calabaricus* Günther, 1866: 266 (original description; Old Calabar [Nigeria]).

**Material:**

601 specimens (16–137 mm SL) from 42 collections.

"Atlantide":
St. 52, off Monrovia, Liberia, I:2:46,--21 (66–97).
St. 53, off Port Marshall, Liberia. P 341908. I:4–7:46,--9 (73–91).
St. 71, Takoradi, Ghana, P. 341916–32. I:17–22:46,--17 (48–85).
St. 77, off Accra, Ghana. P 341937–90. I:24–29:46,--54 (71–105).
St. 111, off Bonny River, Nigeria. P 341992–95. II:22:46,--4 (40–99).
St. 117, off Victoria, Cameroons. P 341998. II:24:46,--1 (60).
St. 137, Luanda, Angola. P 341937–2180 and USNM 188751. III:18–22:46,--243 (58–112).
St. 155, Bathurst, Gambia. P 342257–88. IV:18–24:46,--32 (39–105).

"Galathea":
St. 10, Dakar Harbor, Senegal. P 341495–97. XI:6:50,--3 (43–47).
St. 36, off Accra, Ghana. P 341499–508. XI:22–24:50,--10 (71–120).
St. 49, Isle of Rolas, São Tomé, P. 341510. 0°00′, 6°32′E. XI:29:50,--1 (26).
St. 59, off Victoria, Cameroons. P 341512–54. XII:1:50,--44 (16–60).
St. 102, Luanda Harbor, Angola. P 341555–67. XII:12–16:50,--13 (67–118).

"Guinean Trawling Survey":
USNM 194432. BBC 920–1. Freetown, Sierra Leone. XI:21–22:63,--3 (74–86).
194433. BBC 993. 12°08′N, 17°14′W. XII:12:63,--3 (21–31).
194430. BBC 997. Dakar, Senegal. XII:15:63,--43 (46–83).
199431. BBC 959. Freetown, Sierra Leone. XII:2:63,--1 (94).

SFRS Bardaweel Lagoon, Israel. XI:23:56,--4 (97–112).
Haifa, Israel. 1953–58,--18 (54–107).

BMNH 1935.3.28.9, Haifa, Israel,--1 (91).
1928.11.30.3, between Pt. Said and Damietta, Egypt,-- 1(111).
1925.12.31.20, Port Said, Suez Canal Expedition,--1 (122).
1919.5.10.2, Mahamdiya, 25 mi. SE Port Said. XI:22:16,--1 (137).
1888.5.16.20, Mogadore, Morocco,—1 (129).
1956.9.6.63–64, Lagos, Nigeria,--2 (55–103).
1861.12.29.6, Calabar, Nigeria,--1 (100).
1865.5.3.50–51, West Africa,--2 (60–89).

1874.10.6.4, Gabon,--1 (68).
1905.2.24.2, Angola,--1 (123).
1898.5.30.8.17, Lake Menzaleh, Egypt,--10 (65–92).

TABLE 3. Number of gill rakers in *Hyporhamphus unifasciatus* and populations of *H. picarti.*

| | First arch | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 25 | 26 | 27 | 28 | 29 | 30 | 31 | 32 | 33 | 34 | 35 | 36 | N | x̄ |
| *H. picarti* | | | | | | | | | | | | | | |
| Mediterranean | – | – | – | – | – | 1 | 9 | 8 | 10 | 16 | 1 | 1 | 46 | 32.82 |
| Senegal and Gambia | – | – | – | 1 | 2 | 8 | 17 | 18 | 15 | 6 | 1 | – | 68 | 31.81 |
| Sierra Leone and Liberia | – | – | – | 1 | 2 | 4 | 14 | 8 | 2 | – | 1 | – | 32 | 31.16 |
| Ghana and Nigeria | – | – | – | 2 | 3 | 13 | 25 | 25 | 11 | 10 | 1 | 1 | 91 | 31.68 |
| Angola | – | – | – | – | – | 3 | 10 | 20 | 11 | 4 | 5 | 1 | 54 | 32.41 |
| *H. unifasciatus* | 1 | 8 | 14 | 34 | 53 | 61 | 44 | 32 | 17 | 7 | 3 | – | 274 | 30.00 |

| | Second arch | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 18 | 19 | 20 | 21 | 22 | 23 | 24 | 25 | 26 | 27 | N | x̄ |
| *H. picarti* | | | | | | | | | | | | |
| Mediterranean | – | – | – | – | 1 | 8 | 17 | 14 | 4 | 2 | 46 | 24.39 |
| Senegal and Gambia | – | – | 1 | 2 | 17 | 22 | 15 | 10 | 1 | – | 68 | 23.21 |
| Sierra Leone and Liberia | – | – | – | 2 | 8 | 8 | 12 | 2 | – | – | 32 | 23.13 |
| Ghana and Nigeria | – | – | 1 | 3 | 13 | 31 | 27 | 13 | 2 | 1 | 91 | 23.45 |
| Angola | – | – | – | 1 | 12 | 19 | 18 | 5 | – | – | 55 | 23.25 |
| *H. unifasciatus* | 1 | 2 | 6 | 29 | 51 | 45 | 45 | 32 | 11 | 4 | 226 | 23.08 |

MNHN 58–3, Israel,--1 (80).
4992, Suez,--12 (96–112).
B. 1069, Bône, Algeria,--4 (108–126).
13–50, Côte d'Ivoire,--1 (86).
MRCB 95515, Exp. Atl. Sud. St. 187, 6°01′S, 12°24′E, Banana, Congo. IV:20:49, --1 (55).
80100, Banana, Congo. VII:52,--1 (82).
125112–3, Banana, Congo. 1959,--2 (92).
CU Uncat., Sekondi, Ghana. XII:4:59,--1 (93).
Uncat., Keta, Ghana. XII:30:59,--2 (72–76).
Uncat., Takoradi, Ghana. IV:3:60,--27 (75–88).
CNHM 58871, Port Said, Egypt. II:1914,--2 (94–120).
USNM 188753, Antelias, Lebanon. VIII:28:63,--1 (87).

Table 4. Number of fin rays in *Hyporhamphus unifasciatus* and populations of *H. picarti*.

| | Dorsal rays | | | | | |
|---|---|---|---|---|---|---|
| | 13 | 14 | 15 | 16 | N | x̄ |
| *H. picarti* | | | | | | |
| Mediterranean | 1 | 23 | 14 | 4 | 42 | 14.50 |
| Senegal and Gambia | 1 | 36 | 35 | 5 | 77 | 14.57 |
| Sierra Leone and Liberia | – | 12 | 18 | 1 | 31 | 14.65 |
| Ghana and Nigeria | 1 | 40 | 47 | 1 | 89 | 14.54 |
| Angola | – | 22 | 25 | 5 | 52 | 14.67 |
| *H. unifasciatus* | 3 | 57 | 97 | 13 | 170 | 14.71 |

| | Pectoral rays | | | | |
|---|---|---|---|---|---|
| | 10 | 11 | 12 | N | x̄ |
| *H. picarti* | | | | | |
| Mediterranean | 2 | 32 | – | 34 | 10.9 |
| Senegal and Gambia | 3 | 30 | – | 33 | 10.9 |
| Sierra Leone and Liberia | 2 | 17 | 2 | 21 | 11.0 |
| Ghana and Nigeria | 5 | 47 | 5 | 57 | 11.0 |
| Angola | 4 | 25 | 1 | 30 | 10.9 |
| *H. unifasciatus* | 93 | 79 | 3 | 175 | 10.5 |

| | Anal rays | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | 13 | 14 | 15 | 16 | 17 | 18 | N | x̄ |
| *H. picarti* | | | | | | | | |
| Mediterranean | – | 7 | 14 | 15 | 3 | – | 39 | 15.36 |
| Senegal and Gambia | 1 | 4 | 52 | 19 | – | – | 76 | 15.17 |
| Sierra Leone and Liberia | – | 1 | 13 | 18 | 1 | – | 33 | 15.58 |
| Ghana and Nigeria | – | 9 | 56 | 24 | – | – | 89 | 15.17 |
| Angola | – | 3 | 25 | 26 | – | – | 54 | 15.43 |
| *H. unifasciatus* | – | – | 12 | 77 | 67 | 9 | 165 | 16.44 |

Diagnosis: A species of *Hyporhamphus* without scales covering the dorsal and anal fins; with a moderate number of gill rakers, usually 30–34 on the first arch and 22–25 on the second arch (Table 3); pectoral rays usually 11 (Table 4); a relatively low number of vertebrae, 46–49 (Table 5); the pelvic fins inserted far posteriorly ($P_2$-C distance extended forward usually not reaching to middle of opercle, Table 6).

Types of Nominal Species:

*Hemiramphus picarti* Valenciennes. Lectotype MNHN B. 1069, 117.5 mm SL, Bône, Algeria; Guichenot; herein selected. This specimen bears tag number B. 1069. D 16; A 16; $P_1$ 11–11; $RGR_1$ 9+23 = 32; $RGR_2$ 3+21 = 24; LJL 33.0 mm; $P_1$–$P_2$

TABLE 5. Number of precaudal, caudal, and total vertebrae in *Hyporhamphus unifasciatus* and populations of *H. picarti.*

| | Precaudal | | | | | | N | $\bar{x}$ |
|---|---|---|---|---|---|---|---|---|
| | 30 | 31 | 32 | 33 | 34 | 35 | | |
| *H. picarti* | | | | | | | | |
| Mediterranean | 1 | 11 | 20 | 2 | – | – | 34 | 31.68 |
| Senegal and Gambia | 4 | 47 | 18 | – | – | – | 69 | 31.20 |
| Sierra Leone and Liberia | 6 | 20 | 8 | – | – | – | 34 | 31.06 |
| Ghana | 10 | 45 | 7 | – | – | – | 62 | 30.95 |
| Angola | 10 | 44 | 10 | 1 | – | – | 65 | 31.03 |
| *H. unifasciatus* | – | 1 | 13 | 36 | 39 | 12 | 101 | 33.48 |

| | Caudal | | | | | N | $\bar{x}$ |
|---|---|---|---|---|---|---|---|
| | 15 | 16 | 17 | 18 | 19 | | |
| *H. picarti* | | | | | | | |
| Mediterranean | 1 | 11 | 21 | 1 | – | 34 | 16.65 |
| Senegal and Gambia | 2 | 36 | 30 | 1 | – | 69 | 16.43 |
| Sierra Leone and Liberia | 2 | 13 | 19 | – | – | 34 | 16.50 |
| Ghana | 1 | 33 | 27 | 1 | – | 62 | 16.45 |
| Angola | – | 30 | 34 | 1 | – | 65 | 16.55 |
| *H. unifasciatus* | – | – | 18 | 69 | 14 | 101 | 17.96 |

| | Total | | | | | | | | | N | $\bar{x}$ |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | 46 | 47 | 48 | 49 | 50 | 51 | 52 | 53 | 54 | | |
| *H. picarti* | | | | | | | | | | | |
| Mediterranean | 1 | 2 | 17 | 13 | 1 | – | – | – | – | 34 | 48.32 |
| Senegal and Gambia | 4 | 23 | 36 | 6 | – | – | – | – | – | 69 | 47.64 |
| Sierra Leone and Liberia | 3 | 11 | 18 | 2 | – | – | – | – | – | 34 | 47.56 |
| Ghana | 4 | 32 | 23 | 3 | – | – | – | – | – | 62 | 47.40 |
| Angola | 3 | 27 | 29 | 6 | – | – | – | – | – | 65 | 47.58 |
| *H. unifasciatus* | – | – | – | – | 19 | 41 | 26 | 12 | 3 | 101 | 51.40 |

45.9 mm; $P_2$–C 45.9 mm; $P_2$–C extended forward reaches to anterior portion of pectoral fin base. Paralectotypes, three specimens in the same bottle, 125.5, 119.5, and 107.5 mm. SL.

*Hemiramphus schlegeli* Bleeker. Types not examined.

*Hemiramphus calabaricus* Günther. Lectotype BMNH 1861.12.29.6, 100.2 mm. SL, Old Calabar, Nigeria; herein selected. D 13; A 14; $P_1$ 11–11; $RGR_1$ $9+24 = 33$; $RGR_2$ $4+20 = 24$; LJL 25.0+mm; $P_1$–$P_2$ 39.2 mm; $P_2$–C 40.5 mm; $P_2$-C extended forward falls on posterior tip of preopercle. Paralectotypes BMNH 1865.5.3.50–51 (2, 60–89 mm); West Africa.

Distribution: In the Mediterranean Sea from Lebanon south and west along the northern coast of Africa (TORTONESE, 1952); in the eastern Atlantic from Morocco and Dakar south along the coast of the Gulf of Guinea to Luanda, Angola (Fig. 8).

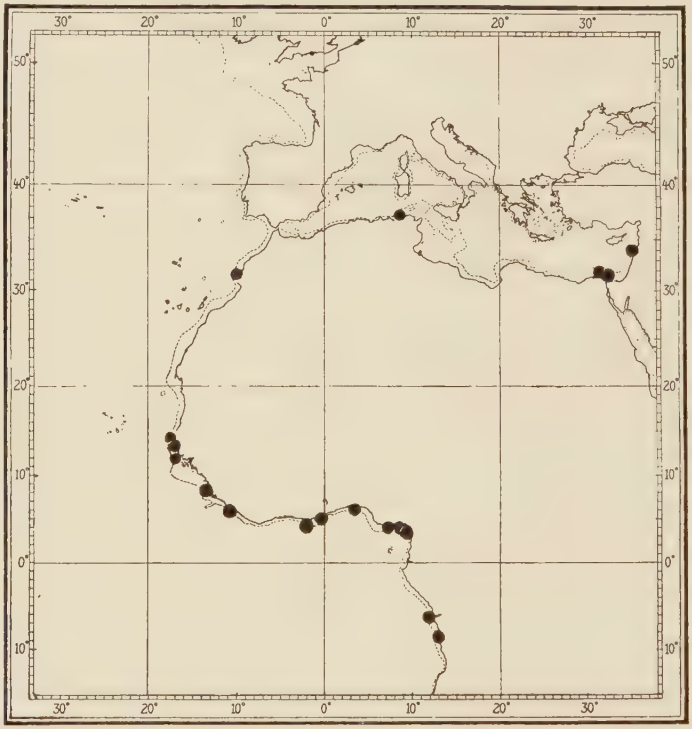

Fig. 8. Distribution of *Hyporhamphus picarti* based on specimens examined.

TABLE 6. Anterior position of pelvic to caudal distance extended forward in *Hyporhamphus unifasciatus* and populations of *H. picarti*.

| | Eye | Pre-opercle | Ant. 1/3 opercle | Mid. 1/3 opercle | Post. 1/3 opercle | Opercle to $P_1$ base | $P_1$ base | Post. to $P_1$ base | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | N | x̄ |
| *H. picarti* | | | | | | | | | | |
| Mediterranean...... | – | – | – | 1 | 20 | 11 | 15 | 2 | 49 | 5.94 |
| Senegal and Gambia. | – | 2 | 4 | 5 | 37 | 12 | 14 | – | 74 | 5.28 |
| Sierra Leone and Liberia......... | – | – | – | – | 14 | 11 | 7 | – | 32 | 5.78 |
| Ghana and Nigeria.. | – | 1 | 1 | 3 | 59 | 25 | 16 | 1 | 106 | 5.49 |
| Angola............ | – | – | 3 | 7 | 30 | 13 | 12 | – | 65 | 5.37 |
| *H. unifasciatus*...... | 88 | 177 | 68 | 22 | 12 | 2 | – | – | 369 | 2.18 |

Discussion: The species of *Hyporhamphus* in the Gulf of Guinea has been called a number of names. GÜNTHER'S *calabaricus* was early recognized as a synonym of BLEEKER'S *schlegeli*. Recent workers (FOWLER, 1936 and POLL, 1953) have considered *schlegeli* to be a synonym of *H. unifasciatus* (Ranzani). *H. unifasciatus* is a distinct species limited to the western Atlantic. It has the dorsal and anal fins densely covered with scales while *picarti* has, at most, five or six scales on the membrane between the first two anal rays, and two or three scales on the membranes between the next few rays. *H. picarti* has the pelvic fins placed farther posteriorly. If the $P_2$-C distance is extended anteriorly from the base of the anterior most pelvic ray, it will usually fall posterior to the middle of the opercle in *H. picarti* and anterior to the middle in *H. unifasciatus* (Table 6). This relationship can also be demonstrated by plotting either $P_1$–$P_2$ or $P_2$–C against standard length. To exaggerate the difference, $P_1$–$P_2$ has been plotted against $P_2$–C (Fig. 9), resulting in almost complete separation of the two species. Meristically *H. picarti* has fewer vertebrae (Table 5), slightly more gill rakers on the first arch (Table 3), modally 11 instead of 10 pectoral rays, and about one less anal ray (Table 4) than does *H. unifasciatus*.

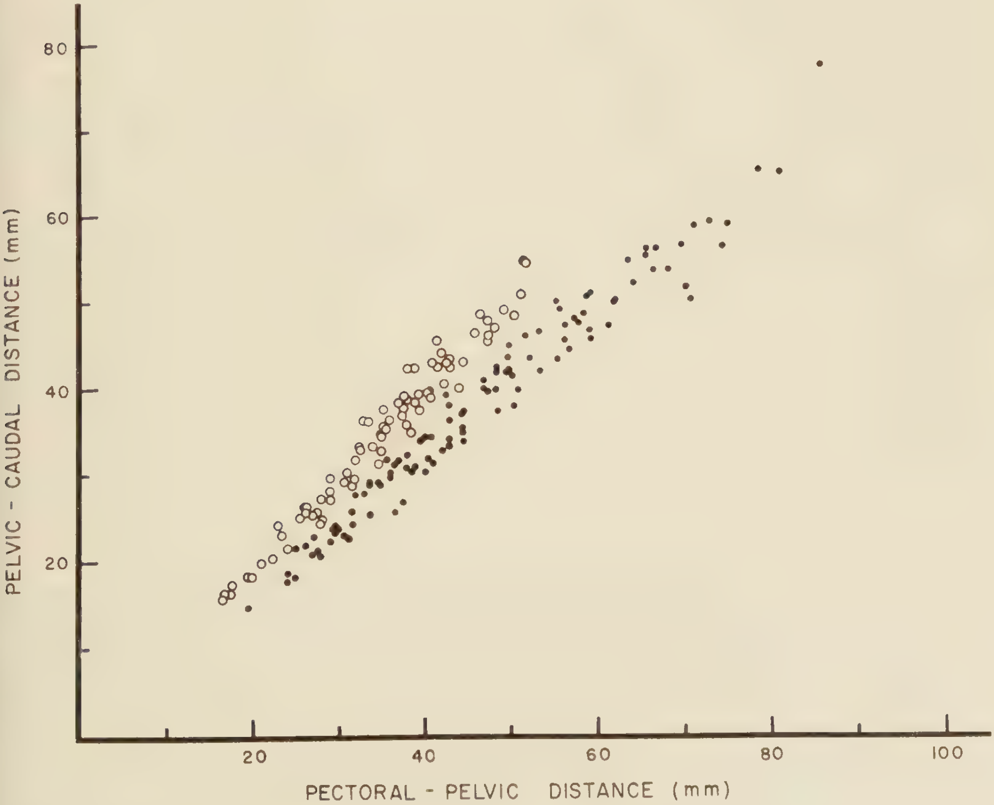

Fig. 9. Pectoral to pelvic distance versus pelvic to caudal distance in *Hyporhamphus*. ● *H. unifasciatus*. ○ *H. picarti*.

A second problem with this species is whether the Gulf of Guinea population *(schlegeli)* is distinct from the Mediterranean population *(picarti)*. To solve this, large series from the extremes of the range within the Gulf of Guinea were compared, Senegal plus Gambia with Angola. After these were found to be identical meristically and morphometrically, comparisons were made between specimens from the Gulf of Guinea and the Mediterranean (Tables 3, 4, 5, 6). There appear to be no significant. differences between these populations, so *schlegeli* is placed in the synonymy of *picarti*.

## REFERENCES

Barnard, K. H., 1925: A monograph of the marine fishes of South Africa.—Ann. S. Afr. Mus. **21**(1): 1–418.

Ben-Tuvia, A., 1953: Mediterranean fishes of Israel.—Sea Fish. Res. Sta. Israel Bull. no. 8: 1–40.

Bleeker, P., 1863: Mémoire sur le poissons de la Côte de Guinée.—Natuurk. Verh. holland. Maatsch. Wet. **2**(18); 136 pp.

Bruun, A. F., 1950: General Report.—Atlantide Rep. **1**: 7–47.

— 1959: General introduction.—Galathea Rep. **1**: 7–48.

Cadenat, J., 1949: Notes sur une petite collection de poissons des Iles du Cap Vert.—Bull. Inst. franç. Afr. noire **11**(3–4): 332–339.

— 1950: Poissons de mer du Sénégal. — Inst. franç. Afr. noire, Dakar, 345 pp.

Collette, B. B., 1962: *Hemiramphus bermudensis*, a new halfbeak from Bermuda, with a survey of endemism in Bermudian shore fishes.—Bull. mar. Sci. Gulf Caribb., **12**(3): 432–449.

Fowler, H. W., 1919: The fishes of the United States Eclipse expedition to West Africa.—Proc. U.S. nat. Mus. **56**: 195–292.

— 1936: The marine fishes of West Africa (based on the collection of the American Museum Congo Expedition, 1909–1915).—Bull. amer. Mus. nat. Hist. **70**(1), 605 pp.

Fowler, H. W. and Steinitz, H., 1956: Fishes from Cyprus, Iran, Iraq, Israel, and Oman.—Bull. Res. Coun. Israel **5B**(3–4): 260–292.

Günther, A., 1866: Catalogue of fishes in the British Museum.—**6**, 368 pp. Taylor and Francis, London.

Le Sueur, C. A., 1823: Observations on several genera and species of fish, belonging to the natural family of the Esoces.—J. Acad. nat. Sci. Philad. **2**(1): 124–138.

Linnaeus, C., 1758: Systema naturae. Regnum animale. 10th ed.—Photographic facsimile printed by Brit. Mus. nat. Hist. 1956, 824 pp.

Parin, N. V., 1964: Taxonomic status, geographical variability and distribution of the oceanic halfbeak, *Euleptorhamphus viridis* (Van Hasselt) (Pisces, Hemirhamphidae).—Trud. Inst. Okean. **73**: 185–203. (In Russian).

Poey, F., 1860: Poissons de Cuba.—Mem. Hist. Nat. Isla Cuba **2**(2): 115–356.

— 1868: Synopsis piscium Cubensium.—Repert. Físico-Natural Isla Cuba **2**: 279–484.

Poll, M., 1953: Poissons III. Téléostéens malacoptérygiens.—Expéd. Océan. Belge Eaux Côt. Afr. Atlan. Sud (1948–1949). Inst. roy. Sci. nat. Belge **4**(2): 1–258.

Tortonese, E., 1952: Gli Hemirhamphidae del Mediterraneo (Pisces, Synentognathi).—Boll. Ist. Mus. Zool. Univ. Torino **3**(3): 1–8.

Valenciennes, A., 1843: Ichthyologie des Iles Canaries.—*In* Webb and Berthelot, Hist. Nat. Iles Canaries *2*, 109 pp.

– 1846: *In* Cuvier and Valenciennes, Histoire Nat. Poissons **19**, 544 pp.

Williams, F., 1964: The Guinean Trawling Survey.—Comm. Fish. Rev. **26**(8): 1–6.

Wolff, T., 1964: The Galathea Expedition 1950–52. List of Benthic Stations from 0–400 Metres, Near-Surface Stations, and Land Stations.—Vidensk. Meddel. Dansk naturh. Foren. Kbhvn. **127**: 195–258.

## Addendum

Since completion of the manuscript, I have examined four specimens of *Hyporhamphus picarti* from Askalan, Israel (ANSP 83550). These were labeled *Hyporhamphus xanthopterus* and are part of the material upon which Fowler and Steinitz (1956) based their Mediterranean record of this species. Dr. Adam Ben-Tuvia has kindly given me permission to quote from his manuscript entitled, »Red Sea fishes recently found in the Mediterranean«, which is now in press in Copeia. He found that the other specimens identified as *H. xanthopterus* by Fowler and Steinitz are also *H. picarti*. Ben-Tuvia reidentified the specimens that he reported as *Hemiramphus gamberur* in 1953 as *Hyporhamphus picarti*. In addition, Ben-Tuvia concluded that »It is probable that all the records of *Hemiramphus marginatus* in the Mediterranean are based on misidentifications.« Thus only two species of Hemiramphidae are known from the Mediterranean: *Hyporhamphus picarti* which is native and *Hemiramphus far* (Forskål) which has come through the Suez Canal.

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## *List of papers resulting in whole or in part from The Atlantide-Expedition to West Africa 1945–1946*

Bigelow, Henry B. & Schroeder, William C. 1950: *Neoharriotta*, new genus.—In: New and little known Cartilaginous Fishes from the Atlantic.—Bull. Mus. Comp. Zoöl. Harvard Coll., vol. 103, No. 7, p. 406. Cambridge, Mass.

Bruun, Anton Fr. 1946: The "Atlantide" Expedition to West Africa 1945–46.—The Danish Foreign Office Journal, No. 3. Copenhagen.

— 1947: Et Trawltræk i Guineabugten. – Dyr i Natur og Museum 1945–46. Copenhagen.

Fraser, F. C. 1947: Sound emitted by Dolphins.– Nature, vol. 160. London.

— 1949: A Specimen of *Sotalia tëuszii Kükenthal* from the Coast of Senegal.– Journ. Mammalogy, vol. 30, No. 3. U.S.A.

Knudsen, Jørgen 1946: Kaskelotfangst ved Açorerne. – Naturens Verden, vol. 30. Copenhagen.

— 1952: Marine Prosobranchs of Tropical West Africa, collected by the "Atlantide" Expedition 1945–46. Part I. – Vidensk. Medd. Dansk naturh. Foren,. vol. 114 pp. 129–185. Copenhagen.

Mortensen, Th. 1948: *Rotula orbiculus* (L.). – In: A Monograph of the Echinoidea. IV, 2, p. 462. Copenhagen.

Wolff, Torben 1959: Biological Results of the Atlantide and Galathea Expeditions. – Centre Belge Océan. Rech. Sousmar., Journées 24 et 25 Févr. 1958, pp. 193–222. Liège.

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# SYSTEMATIC SIGNIFICANCE OF BREEDING TUBERCLES IN FISHES OF THE FAMILY PERCIDAE

*By* BRUCE B. COLLETTE

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# SYSTEMATIC SIGNIFICANCE OF BREEDING TUBERCLES IN FISHES OF THE FAMILY PERCIDAE

*By* Bruce B. Collette[1]

## Introduction

Breeding tubercles are epidermal structures that function primarily in facilitating contact between individuals during spawning. Tubercles are used by some fishes to defend their nests and territories or to protect their body and fin surfaces in nest building. Breeding tubercles are present on species of at least 13 different families of fishes in three orders. Except in the Cyprinidae and Catostomidae, their presence either has been ignored or has been mentioned briefly, with little comment on their biological or systematic importance. The purpose of this study is to survey the Percidae for the presence of breeding tubercles and to compare the different tubercle patterns with the present classification of the family. This paper is the fourth in a series on the systematics of the Percidae (see Collette, 1962, 1963; Collette and Yerger, 1962). A review of the occurrence and significance of breeding tubercles in fishes is currently in preparation.

In view of the large number of reports of breeding tubercles in the Cyprinidae and the Catostomidae, it is somewhat surprising that they have been neglected in the Percidae. Only 13 papers, covering 16 species in 3 genera, report tubercles. I can now triple the number of species and add 2 genera. Jordan's (1877) description of the tubercles on *Percina evides* is the first such record for this family. From 1931 to 1958, tubercles were reported by Vladykov, 1931 (*Zingel streber*); Hubbs and Cannon, 1935 (*Etheostoma serriferum*, *E. gracile*, *E. fusiforme*); Bailey, 1948 (*Percina evides*, *P.* (*Imostoma*) species, *Etheostoma nianguae*); Moore and Cross, 1950 (*Etheostoma cragini*); Moore and Rigney, 1952 (*E. radiosum*); Cross, 1954 (*Percina shumardi*, *Etheostoma gracile*); Hubbs, 1954 (*Percina shumardi*); Cross and Minckley, 1958 (*Etheostoma stigmaeum*); Winn, 1958b (*E. stigmaeum*, *E. microperca*). In recent years, tubercles have been reported by Collette, 1962 (the six species of the subgenus *Hololepis*, adding *Etheostoma zoniferum*, *E. collis*, *E. saludae* to the three noted by Hubbs and Cannon, 1935); Distler and Metcalf, 1962 (*E. pallididorsum*); and Bailey and Richards, 1963 (*E. hopkinsi*).

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METHODS.—In order to find tuberculate material, or to ascertain that a given species is not tuberculate, it was necessary to examine large numbers of specimens. Particular attention was paid to collections made during the spring. Specimens were examined under a binocular microscope and compressed air was used to dry the scales and fin-rays to make the tubercles discernible. The presence of tubercles is ephemeral in many species; therefore the fact that I have not recorded them for a given species does not prove that they do not occur. Gonad development was frequently estimated and recorded, especially in cases where tubercles were not found. The descriptions of breeding tubercles of each species are based on the specimens with the best developed tubercles, although, when adequate collections were available, additional specimens were utilized to trace seasonal development. Catalog numbers, locality, and date of collection are given for at least the best tuberculate material examined of each species.

The study is based upon a survey of the percids in the collections of the U.S. National Museum (USNM), Cornell University (CU), University of Michigan Museum of Zoology (UMMZ), and Tulane University (TU), with additional observations on specimens from the Academy of Natural Sciences of Philadelphia (ANSP), Museum of Comparative Zoology (MCZ), University of Kansas (KU), Virginia Polytechnic Institute (VPI), University of Georgia (UG), University of Mississippi (UM), Illinois Natural History Survey (INHS), University of Texas (TNHC), University of Florida (UF), Florida State University (FSU), and Charles University, Prague. I have examined preserved males in breeding condition of at least 100 the approximately

118 species of Percidae. I also examined nonbreeding material of all species except *Stizostedion marinum.*

Tubercle patterns, together with brief comments on other types of sexual dimorphism, are described, species by species, in the following sections. The suprageneric classification used follows that outlined in a recent paper (Collette, 1963), where the Percidae was divided into two subfamilies, the Luciopercinae and the Percinae. Each of these subfamilies was subdivided into two tribes, the Luciopercini and the Romanichthyini in the first subfamily, and the Percini and Etheostomatini in the second. The arrangement of genera, subgenera, and species within the Etheostomatini (table 1) is modified from that presented by Bailey (*in* Bailey and Gosline, 1955).

For the loan of specimens and other assistance, I wish to thank Edward C. Raney, Cornell University; Robert H. Gibbs, Jr., Ernest A. Lachner, and W. Ralph Taylor, U.S. National Museum; Reeve M. Bailey, University of Michigan; Royal D. Suttkus, Tulane University; Frank B. Cross, University of Kansas; James E. Böhlke, Philadelphia Academy of Natural Sciences; Clark Hubbs, University of Texas; Ota Oliva, Charles University, Prague; Giles W. Mead, Museum of Comparative Zoology, Harvard University; Y. J. McGaha, University of Mississippi; and Robert R. Ross, Virginia Polytechnic Institute. Petru Bănărescu of the Academia Republicii Populare Romine deserves extra thanks for sending specimens of all the Rumanian percids to the museums of the United States. To Robert V. Miller, Rudolph J. Miller, Leslie W. Knapp, and William J. Richards, I owe a special debt of gratitude for their efforts in providing me with data and material on percid breeding tubercles. Without the help of this group of former fellow Cornell students, my work would have been immeasurably more difficult. Mildred H. Carrington has drawn the figures which valuably supplement this paper. Reeve M. Bailey, Daniel M. Cohen, Robert H. Gibbs, Jr., Ernest A. Lachner, and Rudolph J. Miller have all offered valuable suggestions on the manuscript.

## Tribe Luciopercini

### Genus *Stizostedion* Rafinesque

There is little sexual dimorphism in the five species of *Stizostedion*—*canadense* (Smith), *lucioperca* (Linnaeus), *marinum* (Linnaeus), *vitreum* (Mitchill), and *volgense* (Gmelin)—and breeding tubercles are apparently absent. Females of all species reach a larger maximum size than the males and on the average are longer and heavier in a given year class, at least after the first two years of life. For *S. canadense*, see Carlander (1950); for *S. vitreum* see Eschmeyer (1950), Hile (1954)

TABLE 1.—*Distribution of breeding tubercles in the fishes of the family Percidae* (+=present; 0=absent; ?=material not adequate; ♂ and ♀ are placed under areas where tubercles were found: TP?=tubercles present?; Bd=body; A=anal fin; $P_2$=pelvic fins; C=caudal fin; Hd=head; Ch=chin; $P_1$=pectoral fins; D=dorsal fins; Br=branchiostegals)

| Taxon | TP? | Bd | A | $P_2$ | C | Hd | Ch | $P_1$ | D | Br |
|---|---|---|---|---|---|---|---|---|---|---|
| Luciopercini | | | | | | | | | | |
| *Stizostedion* | 0 | – | – | – | – | – | – | – | – | – |
| Romanichthyini | | | | | | | | | | |
| *Zingel* | | | | | | | | | | |
| *asper* | +? | – | – | – | – | – | – | – | – | – |
| *streber* | + | ♂ ♀ | – | – | – | ♂ ♀ | – | ♂ ♀ | – | – |
| *zingel* | + | ♂ ♀ | – | – | – | ♂ ♀ | – | ♂ ♀ | ♂ | – |
| *Romanichthys* | | | | | | | | | | |
| *valsanicola* | + | ♂ ♀ | ♂ | ♂ ♀ | ♂ ♀ | ♂ | – | ♂ ♀ | ♂ | – |
| Percini | | | | | | | | | | |
| *Perca* | 0 | – | – | – | – | – | – | – | – | – |
| *Gymnocephalus* | 0 | – | – | – | – | – | – | – | – | – |
| *Percarina* | 0? | – | – | – | – | – | – | – | – | – |
| Etheostomatini | | | | | | | | | | |
| *Percina* | | | | | | | | | | |
| (*Hypohomus*) | 0 | – | – | – | – | – | – | – | – | – |
| (*Alvordius*) | 0 | – | – | – | – | – | – | – | – | – |
| (*Hadropterus*) | 0 | – | – | – | – | – | – | – | – | – |
| (*Swainia*) | 0 | – | – | – | – | – | – | – | – | – |
| (*Percina*) | | | | | | | | | | |
| *caprodes* | + | ♂ | – | – | – | – | – | – | – | – |
| *rex* | + | ♂ | – | – | – | – | – | – | – | – |
| (*Ericosma*) | | | | | | | | | | |
| *palmaris* | 0 | – | – | – | – | – | – | – | – | – |
| *crassa* | 0 | – | – | – | – | – | – | – | – | – |
| *evides* | + | ♂ | ♂ | ♂ | ♂ | ♂ | ♂ | – | – | ♂ |
| (*Imostoma*) | | | | | | | | | | |
| *shumardi* | + | ♂ | ♂ | ♂ | ♂ | ♂ | – | – | – | – |
| *uranidea* | + | ♂ | ♂ | ♂ | ♂ | ♂ | – | ♂ | – | – |
| (*Cottogaster*) | 0 | – | – | – | – | – | – | – | – | – |
| *Ammocrypta* | | | | | | | | | | |
| (*Crystallaria*) | | | | | | | | | | |
| *asprella* | + | – | ♂ | ♂ | – | – | – | – | – | – |
| (*Ammocrypta*) | | | | | | | | | | |
| *vivax* | + | – | ♂ | ♂ | – | – | – | – | – | – |
| *pellucida* | + | – | – | ♂ | – | – | – | – | – | – |
| *clara* | + | – | ♂ | ♂ | ♂ | – | – | – | – | – |
| *beanii* | + | – | ♂ | ♂ | – | – | – | – | – | – |
| *Etheostoma* | | | | | | | | | | |
| (*Boleosoma*) | | | | | | | | | | |
| *nigrum* | 0 | – | – | – | – | – | – | – | – | – |
| *olmstedi* | 0 | – | – | – | – | – | – | – | – | – |
| *perlongum* | 0 | – | – | – | – | – | – | – | – | – |
| *longimaEum* | 0 | – | – | – | – | – | – | – | – | – |
| *podostemone* | 0 | – | – | – | – | – | – | – | – | – |
| *chlorosomum* | + | – | ♂ | ♂ | – | – | – | – | – | – |
| *stigmaeum* | + | ♂ | ♂ | ♂ | – | – | – | – | – | – |
| *jessiae* | + | ♂ | ♂ | ♂ | – | – | – | – | – | – |
| (*Ioa*) | 0 | – | – | – | – | – | – | – | – | – |
| (*Etheostoma*) | | | | | | | | | | |
| *variatum* | + | ♂ ♀ | – | – | – | – | – | – | – | – |
| *tetrazonum* | + | ♂ ♀ | – | – | – | – | – | – | – | – |
| *euzonum* | + | ♂ ♀ | – | – | – | – | – | – | – | – |

TABLE 1.—Continued

| Taxon | TP? | Bd | A | $P_2$ | C | Hd | Ch | $P_1$ | D | Br |
|---|---|---|---|---|---|---|---|---|---|---|
| Etheostomatini—Continued | | | | | | | | | | |
| *Etheostoma*—Continued | | | | | | | | | | |
| (*Etheostoma*)—Continued | | | | | | | | | | |
| *kanawhae* | + | ♂ ♀ | – | – | – | – | – | – | – | – |
| *osburni* | + | ♂ ♀ | – | – | – | – | – | – | – | – |
| *inscriptum* | + | ♂ | – | – | – | – | – | – | – | – |
| *thalassinum* | + | ♂ | – | – | – | – | – | – | – | – |
| *swannanoa* | + | ♂ | – | – | – | – | – | – | – | – |
| *blennioides* | + | ♂ | – | – | – | – | – | – | – | – |
| *gutselli* | + | ♂ | – | – | – | – | – | – | – | – |
| *blennius* | 0? | – | – | – | – | – | – | – | – | – |
| *sellare* | 0? | – | – | – | – | – | – | – | – | – |
| *rupestre* | 0 | – | – | – | – | – | – | – | – | – |
| *histrio* | 0 | – | – | – | – | – | – | – | – | – |
| *zonale* | 0 | – | – | – | – | – | – | – | – | – |
| (*Ulocentra*) | 0 | – | – | – | – | – | – | – | – | – |
| (*Allohistium*) | 0 | – | – | – | – | – | – | – | – | – |
| (*Nothonotus*) | 0 | – | – | – | – | – | – | – | – | – |
| (*Oligocephalus*) | | | | | | | | | | |
| *nianguae* | + | ♂ | – | – | – | – | – | – | – | – |
| *sagitta* | + | ♂ | – | – | – | – | – | – | – | – |
| *radiosum* | + | ♂ | – | – | – | – | – | – | – | – |
| *whipplii* | + | ♂ | – | – | – | – | – | – | – | – |
| *caeruleum* | + | ♂ | – | – | – | – | – | – | – | – |
| *punctulatum* | + | ♂ | ♂ | ♂ | ♂ | – | – | – | – | – |
| *parvipinne* | + | – | ♂ | – | – | – | – | – | – | – |
| *fricksium* | + | – | ♂ | – | – | – | – | – | – | – |
| *hopkinsi* | + | ♂ | ♂ | ♂ | – | – | – | – | – | – |
| *spectabile* | + | ♂ | ♂ | ♂ | ♂ | – | – | ♂ | – | – |
| *luteovinctum* | + | ♂ | ♂ | ♂ | ♂ | – | – | – | – | – |
| *cragini* | + | ♂ | ♂ | ♂ | – | – | – | – | – | – |
| *pallididorsum* | + | ♂ | ♂ | ♂ | – | – | – | – | – | – |
| *asprigene* | 0 | – | – | – | – | – | – | – | – | – |
| *swaini* | 0 | – | – | – | – | – | – | – | – | – |
| *mariae* | 0 | – | – | – | – | – | – | – | – | – |
| *juliae* | 0 | – | – | – | – | – | – | – | – | – |
| *pottsii* | 0 | – | – | – | – | – | – | – | – | – |
| *lepidum* | 0 | – | – | – | – | – | – | – | – | – |
| *exile* | 0 | – | – | – | – | – | – | – | – | – |
| *grahami* | 0 | – | – | – | – | – | – | – | – | – |
| (*Villora*) | 0 | – | – | – | – | – | – | – | – | – |
| (*Austroperca*) | ? | – | – | – | – | – | – | – | – | – |
| (*Psychromaster*) | 0 | – | – | – | – | – | – | – | – | – |
| (*Catonotus*) | 0 | – | – | – | – | – | – | – | – | – |
| (*Hololepis*) | | | | | | | | | | |
| *serriferum* | + | – | ♂ | ♂ | – | – | – | – | – | – |
| *gracile* | + | – | ♂ | ♂ | – | – | ♂ | – | – | – |
| *zoniferum* | + | – | ♂ | ♂ | – | – | ♂ | – | – | – |
| *fusiforme* | + | – | ♂ | ♂ | – | – | – | – | – | – |
| *saludae* | + | – | ♂ | ♂ | – | – | – | – | – | – |
| *collis* | + | – | ♂ | ♂ | – | – | – | – | – | – |
| (*Microperca*) | | | | | | | | | | |
| *proeliare* | + | – | ♂ | ♂ | – | – | – | – | – | – |
| *microperca* | + | – | ♂ | ♂ | – | – | – | – | – | – |
| *fonticola* | + | – | ♂ | ♂ | – | – | – | – | – | – |

and Rawson (1957); and for the three European species, see data presented by Berg (1949). Vladykov (1931) and Oliva (1953) reported that males of *S. lucioperca* have relatively longer fins than the females. Vladykov (1931) noted the same for *S. volgense.*

## Tribe Romanichthyini

### Genus *Zingel* Cloquet

There are three species in this genus: *asper* (Linnaeus), *streber* (Siebold), and *zingel* (Linnaeus). Both sexes of *Z. streber* and *Z. zingel* are tuberculate; *Z. asper* also will probably be found to be so.

I have examined 10 tuberculate males of *Zingel streber* (ANSP 82497, Rumania, Mures R., 108 mm.; USNM 187742, Rumania, Criscul R., 57–108 mm.; and USNM 190212, Rumania, Timis R., 98–99 mm.), all collected in October, and 9 tuberculate females from the same collections, plus USNM 187740 (Criscul R., April, 131 mm.). In the male, where they are best developed (USNM 190212, 99 mm.), tubercles are present on all the head scales including those on the opercle and preopercle. These tubercles are elongated longitudinally with the point of the tubercle projecting upward and posteriorly beyond the margin of the scale. A few head scales have two tubercles per scale, but the majority only have one. Prominent ridgelike tubercles are developed on all the body scales above the lateral line posterior as far as the middle of the caudal peduncle. They are also present on several rows of scales below the lateral line in the region posterior to the tip of the pectoral fin. The females and the other males have a similar pattern of tubercle development, but the tubercles are more ridgelike and less prominent and are not on as many scales. The individual tubercles are aligned in the same direction from one scale to the next, creating continuous ridges along the body. Among the Percidae, this condition is unique in the genus *Zingel.* None of the tuberculate specimens show any sign of tubercles on any of the fins. Rudolph J. Miller examined a 150 mm. gravid tuberculate female of *Z. streber* (Charles University No. 9908, Czechoslovakia, Orawa R., April 4) and he corroborates what I have found, although the tubercles seem to have been somewhat better developed than in the females I examined. Vladykov (1931) reported that *Zingel streber* had tubercles on the pectoral fins as well as on the head and the body.

I have examined one tuberculate specimen of *Zingel zingel*, a 175 mm. male that Dr. Miller found for me (Charles University no. 4514, Czechoslovakia, Danube R., May 5). There are tubercles on all the head scales and on the dorsal and dorsolateral body scales. These tubercles are only slightly raised and do not form longitudinal rows as they do in *Z. streber.* There are tubercles on the anterior ten rays in the second dorsal fin and on the anterior surface of the upper pectoral rays. None are present on the first dorsal, anal, or pelvic fins. Two other males with greatly enlarged testes (MCZ 3063) and 7 egg-filled females (USNM, MCZ, ANSP) lack tubercles. Dr. Miller also examined a large female *Z. zingel* in the Charles University collection which had poorly developed tubercles on the head scales, scales of the anterior dorsum, and on the pectoral rays. Vladykov (1931) reported that sexual dimorphism was rather marked in this species, but only mentioned that the paired fins of the males were much longer than those of the females.

I examined one male of *Zingel asper* with well-developed testes (ANSP 14055, France, Rhone R., 116 mm.) and one female filled with large eggs (MCZ 2551, Saone R., 105 mm.). Neither had any breeding tubercles. Both specimens, however, were in poor condition, and *Z. asper* will probably be found to have a tubercle distribution very similar to that of its close relative *Z. streber*.

### Genus *Romanichthys* Dumitrescu, Bănărescu, and Stoica

I have examined four tuberculate males of the only species in this genus, *Romanichthys valsanicola* Dumitrescu, Bănărescu, and Stoica (USNM 190149, Arges R., May 22, 66 mm.; USNM 187749, Arges R., May–June, 68 mm.; MCZ 40966, Vilsan R., June–Aug., 85 mm.; and UMMZ uncat., Arges R., June–July, 76 mm.) and two tuberculate females (MCZ 40966, 86 mm. and UMMZ uncat., 69 mm.). Another male (USNM 190180, 92 mm., June–Aug.) has well-developed testes but lacks tubercles. Four females (USNM 190149, 96 mm.; MCZ 40966, 80 and 89 mm.; and UMMZ uncat., Vilsan R., Oct. 19, 65 mm.) also lack tubercles. The tubercles are best developed in the smaller USNM male (fig. 1). There are a few small tubercles distally on the dorsal surface of pelvic soft rays 2–5 and ventrally on rays 3–5.

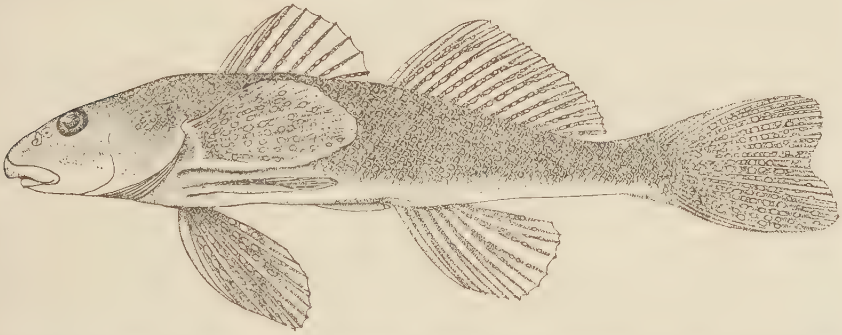

FIGURE 1.—Male of *Romanichthys valsanicola* showing the distribution of breeding tubercles (USNM 190149, Rumania, Arges River, May 22, 66 mm. SL).

Tubercles are present along the outside of the pectoral fin on the upper 10–11 rays and on the inside on the lower 2–6 rays. The tubercles on the outer surface are longer and relatively low; those on the inner surface are smaller and more conical. Tubercles are present on the upper principal caudal rays, on the dorsal 3–4 rays of the lower half of the caudal fin, and on the last three anal soft rays. Tubercles are developed distally on all but the first two dorsal spines and on the entire length of the second dorsal rays. This is the only percid with tubercles on both dorsal fins. A low conical tubercle is present in the center of most of the exposed body scales, although the tubercles are smaller on the ventral side of the caudal peduncle. Tubercles also are present on the dorsal half of the opercle. In many ways, the overall appearance of the body tubercles on this specimen is reminiscent of the tubercle pattern of the minnow *Campostoma anomalum* (see color plate, Forbes and Richardson, 1909). One tuberculate female of *R. valsanicola* (MCZ 40966) has small tubercles on many of the body scales, the distal parts of the pectoral rays, the distal tip of pelvic soft ray 4 (dorsal surface), and a few scattered tubercles on the upper caudal fin rays. Another (UMMZ uncat.) has only a few poorly developed tubercles on the pectoral rays. In the lengthy original description of this genus and species (Dumitrescu, Bănărescu, and Stoica, 1957) there was no mention of breeding tubercles.

## Tribe Percini

### Genus *Perca* Linnaeus

There is little sexual dimorphism in the three species of *Perca: flavescens* (Mitchill), *fluviatilis* Linnaeus, and *schrenki* Kessler. I have found no indication of breeding tubercles in sexually mature specimens of *P. flavescens* or P. *fluviatilis*. There are no tubercles on the single available male of *P. schrenki* (USNM 55712), which has greatly enlarged testes. In *P. flavescens* of corresponding age, the modal and average lengths of females exceed those of males (Hile and Jobes, 1942; Beckman, 1949; Jobes, 1952). Females of *P. fluviatilis* likewise are larger than males (Berg, 1949; Alm, 1952). Vladykov (1931) and Oliva (1953) found that the paired fins of *P. fluviatilis* are longer in males than in females.

### Genus *Gymnocephalus* Bloch

There is sexual dimorphism in *Gymnocephalus*. Males of *G. cernua* (Linnaeus) and *G. schraetser* (Linnaeus) are smaller than females (Vladykov, 1931; Oliva, 1953) and the paired fins of the males are somewhat longer. There are no tubercles on nine males of

*Gymnocephalus cernua* (USNM, UMMZ; 60–87 mm.) with greatly enlarged testes or on 20 egg-filled females (68–158 mm.) from these and nine other USNM collections. Tubercles are absent from five males of *G. schraetser* (ANSP, UMMZ, USNM; 92–117 mm.) with greatly enlarged testes and from nine egg-filled females (105–155 mm.). Smitt (1892, p. 42) reported that there was little external distinction between males and females of *Gymnocephalus acerina* (Güldenstädt). He found that males had longer pelvic fins and deeper bodies than females, but he did not mention breeding tubercles. The one specimen available to me (USNM 28564) is an egg-filled female lacking tubercles.

### Genus *Percarina* Nordmann

I have examined three specimens of *Percarina demidoffi* Nordmann (USNM 37308 and MCZ 26527). All are females filled with eggs. All lack tubercles.

## Tribe Etheostomatini

The darter tribe is the most speciose in the family, with 102 valid described species, plus about a dozen undescribed ones. Bailey (*in* Bailey, Winn, and Smith, 1954; and *in* Bailey and Gosline, 1955) has recently reduced the nominal genera of darters to three: *Percina* (22 species in 8 subgenera), *Ammocrypta* ( 5 species in two subgenera), and *Etheostoma* (76 species in 13 subgenera). Several changes within subgenera, based on tubercle patterns, seem necessary, especially in the subgenera *Ericosma*, *Boleosoma*, *Ioa*, *Etheostoma*, and *Oligocephalus*. I hesitate to make nomenclatorial changes based primarily on breeding tubercle patterns, and in this paper I shall merely discuss some of the groups in which reallocation seems desirable.

### Genus *Percina*

#### Subgenus *Hypohomus* Cope

This subgenus contains three species: *aurantiaca* (Cope), *cymatotaenia* (Gilbert and Meek), and one undescribed species. Males apparently lack breeding tubercles, although a unique adaptation probably performs the same function. Bailey (1948) pointed out that males of *Hypohomus* have a thin flangelike midventral keel on the lower edge of the caudal peduncle near the caudal base bearing strongly developed ctenoid scales. This seems especially significant, because males of the subgenus *Hypohomus* have the fewest enlarged midventral scales of any of the subgenera of *Percina*. It will be interesting to see how these keels function in spawning.

Males of *P. aurantiaca* in 7 collections (UMMZ, USNM), taken from April 19 through October 3, lack tubercles. One of these specimens, a 132 mm. male taken April 29 (UMMZ 129572, Tennessee, Little Pigeon R.), has greatly enlarged testes and appears to be near spawning condition. No males of *P. cymatotaenia* collected in the spring were examined, but a 69 mm. male taken on August 26 (UMMZ 152290, Mo., Gasconade R.) has slightly enlarged testes and a well-developed caudal keel. The ventral scales of this specimen have well developed ctenii, making the venter very rough to the touch. The best-developed caudal keels I have observed were pointed out to me by Reeve M. Bailey and are in three males of the undescribed species of *Hypohomus* (UMMZ 165304, Kentucky, Green R., April 5, 50–65 mm.). They are covered with ctenoid scales resembling the modified midventral scales usually present in males of *Percina*. The anal fin of these males, considerably longer than that of the two females in the same collection, reaches to the base of the caudal, thus connecting it with the caudal keel and apparently forming a single functional unit.

### Subgenus *Alvordius* Girard

There are five species in this subgenus: *macrocephala* (Cope), *maculata* (Girard), *notogramma* (Raney and Hubbs), *pantherina* (Moore and Reeves), and *peltata* (Stauffer). I have examined adequate breeding material of the last four species and have found no tubercles. Males have enlarged midventral scales and considerably more pigment in the first dorsal fin than the females have. Both sexes of *P. maculata* are equal in size. The males lack breeding tubercles, but the genital papillae of the females are elongate, broad, and tubelike (Winn, 1958b, p. 172). Petravicz (1938) did not mention breeding tubercles in this species. *P. maculata* spawns over sand or gravel, with the male mounted on the female's back (Winn, 1958b, fig. 4). *P. peltata* spawns in a similar manner, but the male's caudal peduncle does not lie alongside the female's, as is the case of most darters. The enlarged caducus scales on the male belly apparently serve both to stimulate the female and to enable the male to maintain his position over her (New, 1963; and pers. comm.).

### Subgenus *Hadropterus* Agassiz

There are three described species in this subgenus: *nigrofasciata* (Agassiz), *sciera* (Swain), and *lenticula* Richards and Knapp. There are no tubercles on specimens taken in six March–April collections of *P. nigrofasciata* from Georgia, Alabama, and Mississippi. The ovaries and testes of these specimens are greatly enlarged, indicating that they are close to spawning condition. Several of the males are extremely darkly pigmented. Crawford (1956) thus describes sexual dimorphism in *P. n. nigrofasciata:* The males are larger and darker than females; the vertical bars of the males tend to be more discrete and less confluent; enlarged ctenoid scales are present along the midventral line on the males' bellies; and the genital papillae in the females are long, conical, and clearly villiform.

No tubercles are present on specimens of *P. sciera* in three Oklahoma–Texas collections taken in March and April. The testes and ovaries of all these specimens are greatly enlarged. The vertical banding present in the females becomes completely obscured by the dark pigment in breeding males. The fins, belly, and breast are almost black in these males. Males have enlarged scales along the midventral line of their bellies.

There are no tubercles on the two males of the recently described *P. lenticula* collected in the spring (CU 43592, Alabama drainage, May 9, 96 mm., holotype; CU 43594, Alabama drainage, May 17, 86 mm., paratype). There is little sexual dimorphism in color pattern (Richards and Knapp, 1963).

### Subgenus *Swainia* Jordan and Evermann

There are four species in this subgenus: *nasuta* (Bailey), *oxyrhyncha* (Hubbs and Raney), *phoxocephala* (Nelson), and *squamata* (Gilbert and Swain). I have examined 15 collections of *P. phoxocephala* taken from mid-March to September (UMMZ, USNM, KU), a male of *oxyrhyncha* taken on June 25 (UMMZ 118422, holotype), a male of *squamata* taken on May 25 (UMMZ 177816), and 5 males of *nasuta* taken on April 26 (CU 41971), and have found no tubercles. Trautman (1957, p. 543) reported that breeding males of *P. phoxocephala* are more intensely colored than females and have orange bands on the first dorsal fin.

### Subgenus *Percina* Haldeman

There are two species in this subgenus: *caprodes* (Rafinesque), with several subspecies, and *rex* (Jordan and Evermann). Tubercles are present on the ventral scale rows of the males of both species. Tubercles seem to be better developed and present for a longer period in southern populations, *Percina caprodes carbonaria* (Baird and Girard), than in northern ones. Both species have low rounded tubercles on the posterior part of the scales. The tubercles are usually not prominent, so that magnification and drying are necessary to trace their extent. No fin tubercles were found, and the females lack tubercles altogether.

Specimens with tubercles of *P. caprodes carbonaria* have been found in five collections, dating from April 14 (CU 32822, Missouri, Lamine R.) to May 18 (TU 15493, Arkansas, Arkansas R.). Tubercles were found on males of *P. c. caprodes* × *P. c. semifasciata* (DeKay) intergrades taken April 20 (CU 8238, Pennsylvania, Shenango R., 88–110 mm. standard length). A male *P. caprodes* with well-developed tubercles (TU 15493, 102 mm.) had tubercles on the modified midventral scales, 5 rows on each side of the modified midventral row, 8 rows per side just anterior to the genital papilla, 4 rows along each side of the anal fin base, and 11 ventral caudal peduncle rows. The pelvic and anal fins and the venter of females lack pigment; these areas are darkened in males. Winn (1958b, p. 172) reported that both sexes of Michigan *P. caprodes* were of equal size, that the anal fins of males were larger than those of females, and that breeding tubercles were absent.

In spawning, the female *P. caprodes* stops over sand or gravel ahead of a male. The male swims up and mounts her with his pelvic fins over her relaxed first dorsal fin and his tuberculate lower sides in contact with her sides (Reighard, 1913; Winn, 1958a; 1958b, fig. 4). Sometimes accessory males vibrate with the spawning pair (Winn, 1958a).

One tuberculate male of *Percina rex* was examined (CU 16910, Virginia, Roanoke R., March 27, 105 mm.). It has tubercles on 2–3 rows of scales on each side of the midventral row and on the posterior ventral portion of the caudal peduncle. A female and a smaller male from this collection lack tubercles.

### Subgenus *Ericosma* Jordan and Copeland

Three species are presently placed in this subgenus: *evides* (Jordan and Copeland), *crassa* (Jordan and Brayton), and *palmaris* (Bailey). The two latter species apparently lack tubercles, but males of *P. evides* have well-developed tubercles on numerous parts of the body (fig. 2). Jordan's (1877) discovery of tubercles on the pelvic and anal fins of *P. evides* was the first record of tubercles in the Percidae. Bailey (1948) also noted tubercles on the lower fins of this species.

Tubercles are present on males of *P. evides* in several collections taken from March 10 (UMMZ 103459, Tennessee, Clinch R.) to June 29 (UMMZ 131458, North Carolina, Swain Co.). Tubercles are present on the ventral surfaces of all pelvic soft rays (but apparently are absent from the spine), dorsally on the distal parts of pelvic soft rays 1–3, and laterally on the anal spines and soft rays. The tubercles are quite small and conical and, lacking pigment, stand out in contrast to the darkly pigmented fins. In males with maximum tubercle development (CU 38055 and CU 38127, Georgia, Toccoa R., June 7) tubercles are present on most ventral scale rows posterior to the pelvic fins and below the lateral line. A few tubercles are present on some of the lateral line scales. The modified midventral scales have up to three tubercles per scale. This, with *P. uranidea* and *P. caprodes*, is one of the few darters in which tubercles are present on these scales and is the only species in which there is more than one tubercle per scale. If the midventral scales function in a manner analagous to the breeding tubercles, the possession of both tubercles and the modified scales seems unnecessary. It will be interesting to learn how these structures function in the courtship-spawning act. Tubercles are present on some rays of the ventral half of the caudal fin. The cephalic pores of the preoperculomandibular and infraorbital canals are sites for small tubercles. These tubercles extend onto the chin beside the pores of the anterior portion of the preoperculomandibular canal, as in *Etheostoma* (*Hololepis*) *gracile* and *E.* (*H.*) *zoniferum*. Tubercles are present on some of the branchiostegal rays, a condition unique among the Percidae, although known for some Cyprinidae. Small scattered tubercles are present on parts of the opercle.

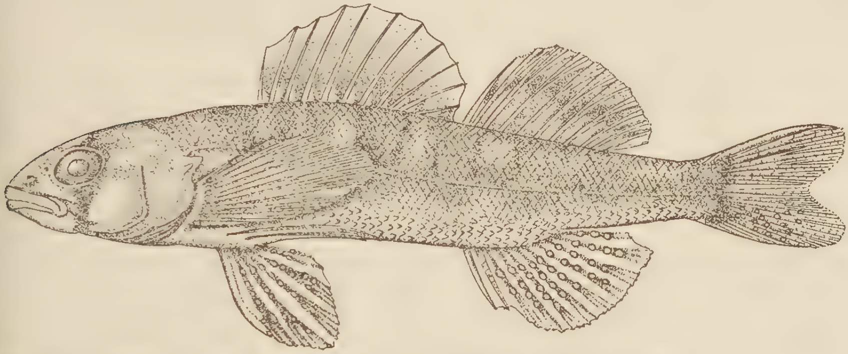

FIGURE 2.—Male of *Percina* (*Ericosma*) *evides* showing the distribution of breeding tubercles (USNM 44433, Indiana, Tippecanoe River, May 16, 53 mm. SL).

Among the Percinae, only *Percina* (*Imostoma*) *uranidea* has a tubercle distribution which approaches that of *P. evides*. *Romanichthys* and *Zingel* in the Luciopercinae have large numbers of tubercles on the head, concentrated on top.

Tubercles are absent on specimens of *P. crassa* in several March and April collections (UMMZ), although the males have greatly enlarged testes and the females are filled with large eggs. Eight males of *P. palmaris* taken on March 31 (CU 17328, Georgia, Talking Rock Cr.) appear to be in full breeding color, but they lack breeding tubercles, although fleshy ridges similar to those in *Etheostoma*

(*Oligocephalus*) *nianguae* are well developed on the anal elements and, to a lesser degree, on the ventral surfaces of the pelvic rays. Lack of tubercles may indicate that these two species are not as closely related to *P. evides* as was indicated by Bailey (1940; and *in* Bailey and Gosline, 1955).

### Subgenus *Imostoma* Jordan

There are two species in this subgenus: *shumardi* (Girard) and *uranidea* (Jordan and Gilbert). Males of both species have tubercles on many areas and have the anal fin greatly elongated so that it reaches to the caudal base. Bailey (1948) reported tubercles on the lower fins of "the several species" of *Imostoma.*

Tubercles are present on males of *P. shumardi* taken from January 12 (TU 14902, Mississippi, Pearl R.) to July 7 (USNM 44432, Indiana, Wabash R.). At maximum development (USNM 187775, Texas, Guadalupe R., Feb. 4, 47–56 mm.; UMMZ 81563, Michigan, Au Sable R., April 30, 38–45 mm.; and KU 3208, Kansas, Neosho R., April 10, 49–51 mm.) large high tubercles are present on the entire length of the anal soft rays. Small tubercles are present on the second anal spine. Tubercles are present on the entire length of the ventral surface of pelvic soft rays 1–2 or 2–3 and on the distal tip of rays 3–4. Tubercles cover the entire length of the most ventral five principal rays of the caudal fin and a few are found on the distal tips of the next two rays. Cross (1954) reported tubercles on the anal and caudal fins of the KU specimens. In a 55 mm. male from USNM 187775, a small tubercle is also present on the posterior portion of each of the midventral scales, in addition to a few tubercles above the upper jaw next to the openings of the infraorbital canal and a few scattered tubercles on the posterior portions of the preopercle and opercle. Tubercles are better developed on larger males as shown by TU 14902, in which three males, 59–67 mm. long, lack tubercles and three males, 62–70 mm., have well-developed tubercles. Hubbs (1954) has noted elongate tubercles on the anal rays of mature males.

*P. uranidea* is even more tuberculate than *P. shumardi*, and is exceeded in the Percidae only by *Romanichthys valsanicola* and *P.* (*Ericosma*) *evides.* At maximum tubercle development, males have tubercles on almost all surfaces of the ventral half of the body (fig. 3). The tubercles on the anal fin closely resemble those on *P. shumardi* and are found at maximum development on the distal half to three-fourths of all anal soft rays. Similar tubercles are present on the ventral surface of all the elements of the pelvic fin, but they are larger and better developed on the soft rays than on the spine. Although they are also present on the dorsal surface, they are less numerous and tend to be confined to the distal portion of the soft rays. Tubercles sometimes are developed on the few imbedded breast scales, the modified midventral scales, many of the scale rows lateral to the midventral rows, and on the ventral rows of caudal peduncle scales. As in *P. shumardi* and *P. evides*, small tubercles develop near the pores of the infraorbital and preoperculomandibular canals. Small tubercles are present along some of the rays of the ventral half of the caudal fin. A few specimens have tubercles developed on the ventral 2–5 rays of the pectoral fin, a condition found only in one other species of the Etheostomatini, *Etheostoma* (*Oligocephalus*) *spectabile*.

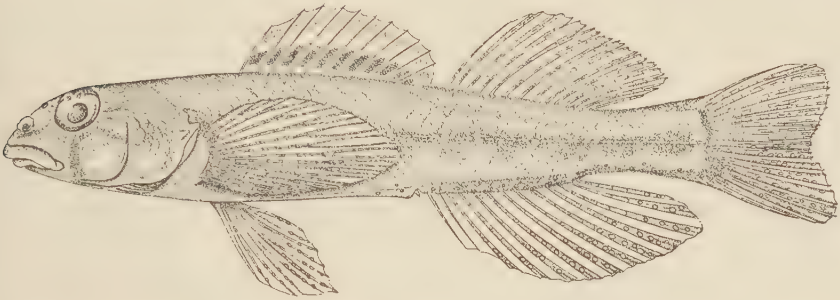

FIGURE 3.—Male of *Percina* (*Imostoma*) *uranidea* showing the distribution of breeding tubercles (TU 7965, Louisiana, Pearl River, Feb. 16, 50 mm. SL).

The abundant material of *P. uranidea* in the Tulane University collections taken throughout the year from Pearl River makes a study of the annual development of the breeding tubercles possible. Maximum development occurs from February 8–16 (table 2), when the peak of spawning most likely occurs.

TABLE 2.—*Development of breeding tubercles in males of* Percina (Imostoma) uranidea *from the Pearl River* (see table 1 for abbreviations; L. Caud.=lower caudal fin)

| Dates | Tubercle distribution | | | | | |
|---|---|---|---|---|---|---|
| | A | $P_2$ | L. caud. | Bd | $P_1$ | Hd |
| November 3 | – | – | – | – | – | – |
| December 8 | + | + | – | – | – | – |
| January 28 | + | + | – | – | – | – |
| February 3 | + | + | + | – | – | – |
| February 8–16 | + | + | + | + | + | + |
| March 9 | + | + | + | + | – | – |
| March 28 | + | + | + | – | – | – |
| April 3 | + | + | – | – | – | – |
| April 10 | + | + | – | – | – | – |
| May 8 | – | – | – | – | – | – |
| May 23 | – | – | – | – | – | – |

### Subgenus *Cottogaster* Putnam

*P. copelandi* (Jordan) is the only known species. I have examined three large collections (USNM) from June, July, and August, an April collection from Pearl River (TU 17732), and several additional collections taken from February through July (UMMZ), and have found no tubercles. The ovaries and testes of these specimens are greatly enlarged. Males have melanophores concentrated in the center of each of the membranes of the first dorsal fin; they have much darker pelvic fins and somewhat darker second dorsal and anal fins, belly, and breast, than the females. Males have 5–12 enlarged midventral scales. Winn (1953, 1958b) reported that males were larger and more heavily pigmented than females, had larger anal fins, and lacked breeding tubercles. The genital papilla of the breeding female is elongate and tubelike. *P. copelandi* spawns over gravel with the male mounted on the female's back (Winn, 1953; 1958b, fig. 4).

### Genus *Ammocrypta* Jordan

This genus contains two subgenera: *Crystallaria* Jordan and Gilbert, with a single species, *asprella* (Jordan), and *Ammocrypta* Jordan, with four species, *vivax* Hay, *pellucida* (Agassiz), *clara* (Jordan and Meek), and *beanii* Jordan. Males of all five species probably will be found to have tubercles on the rays of the anal and pelvic fins, confirming the synonymizing of *Crystallaria* under *Ammocrypta* on the basis of tubercle distribution.

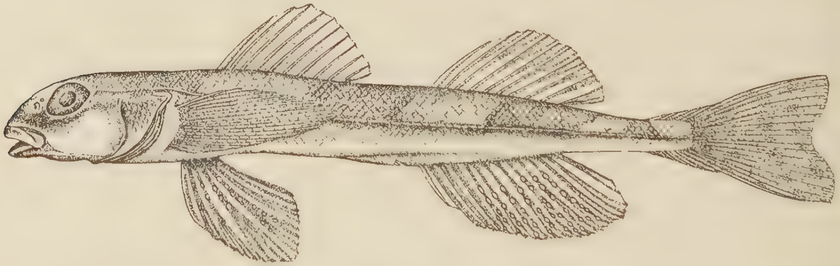

FIGURE 4.—Male of *Ammocrypta* (*Crystallaria*) *asprella* showing the distribution of breeding tubercles (USNM 172363, Louisiana, Ouachita River, Jan. 28, 75 mm. SL).

Tubercles on *A. asprella* begin to develop by late November (TU 1851, Mississippi, Pearl R.), when they are noticeable on the anal spine and the first nine anal soft rays. The maximum development (fig. 4) I have found occurs in the latter half of January (TU 7536, 14921, 15174; Mississippi, Pearl R.; USNM 172363, Louisiana, Ouachita R.). Large conical tubercles are developed on the spine and all the anal soft rays except the last 1–3. In these specimens tubercles are present only on the ventral surface of pelvic soft rays

–5, but they may be found on the other pelvic fin elements when nore material (probably February specimens) is examined.

Males of *A. beanii* develop tubercles on the ventral surface of the elvic spine and on soft rays 1–4 by March 9 (TU 3843, Louisiana, earl R.). By April 26 (TU 19992, Mississippi, Homochitto R.), nuch larger tubercles are present on the ventral surface of all the elvic elements and on the distal eighth to two-thirds of all the anal oft rays, but not on the anal spine. A few tubercles are present istally on the dorsal surface of pelvic soft rays 1–3. A male taken n August 17 (TU 24061, Florida, Yellow R.) also has this tubercle istribution, but the tubercles are smaller.

Breeding tubercles are present on males of *A. clara* from as early as une 20 (UMMZ 127887, Arkansas, Saline R., 32–35 mm.) until uly 28 (UMMZ 148570, Missouri, Salt R., 38–43 mm.). At the naximum development I have seen (UMMZ 148570), small tubercles re present on the entire length of the ventral surface of the pelvic pine and soft rays. Similar tubercles are present on the distal alf to three-fourths of the anal soft rays, but none are developed on he spine. The ventralmost two primary caudal rays have tubercles.

A tubercle distribution similar to that of *A. beanii* was found on nales of *A. vivax* taken May 13 (USNM 172539, Louisiana, Red R.) and July 29 (USNM 172557, Louisiana, Red R.).

Tubercles were present on the pelvic rays of males of *A. pellucida* n three collections (UMMZ 100864, Indiana, Salomonie R., May 31; UMMZ 107758, Ohio, Salt Cr., June 8; CU 32967, Ohio, Big Darby r., Aug. 22). Additional material will probably show the presence f tubercles on the anal fin also.

## Genus *Etheostoma*

### Subgenus *Boleosoma* DeKay

This subgenus can be divided into two or three species groups. The *nigrum* group includes five species: *nigrum* Rafinesque, *longimanum* Jordan, *olmstedi* Storer, *perlongum* (Hubbs and Raney), and *odostemone* Jordan and Jenkins. Breeding tubercles do not develop n these species, the tips of the pelvic spines become swollen during he breeding season, and the males have only brown and black igmentation. These species have a complex spawning behavior nder rocks. The second group is comprised of two closely related pecies: *E. stigmaeum* (Jordan) and *E. jessiae* (Jordan and Brayton). Males of both of these species develop breeding tubercles on the elvic and anal fins. In addition, they also have tubercles on the entral scale rows as in the *E.* (*Etheostoma*) *variatum* species group. Males are brightly colored during the breeding season. *E. stigmaeum* spawns with the male mounted on the female's back like most darters. The third group includes *E. chlorosomum* (Hay), males of which have tubercles on the pelvic and anal fin rays only. Thus, on these criteria, the subgenus *Boleosoma* is not a natural group. In some respects the *nigrum* group is closer to the subgenus *Ioa* than to the *stigmaeum* group, although *E. chlorosomum* is somewhat intermediate between the two groups of *Boleosoma*.

Cole (1957) noted that, as the spawning season for *E. nigrum nigrum* approached, the body became blackened; the W and X lateral markings became darker and appeared as diffuse blotches; the dorsal saddles became less pronounced; the head and lips became black; lines and spots on much of the body tended to disappear; the pelvic and anal elements became heavily blackened and the membranes became only slightly less blackened; the pectoral, dorsals, and caudal darkened; the pelvic spine and the first two or three rays and the more ventral elements of the pectoral fin acquired whitened knoblike tips. This tendency is shown to an extreme degree by one of Cole's (1957) undescribed subspecies of *E. nigrum*, in which the lower pectoral membranes became separated at the tips of the rays in the breeding males and females and ended in large, fleshy, whitish knobs. These knobs apparently serve to protect the tips of the rays during spawning and nest defense. Winn (1958b, p. 172) reported that males of *E. nigrum nigrum* were larger than females and had larger anal, first dorsal, second dorsal, pectoral, and pelvic fins, and had the first four or five spines of the first dorsal fin adorned with thickened, opaque, white tips. *E. n. nigrum* spawns upside down underneath rocks and the male subsequently defends the nest (Winn, 1958a; 1958b, fig. 5).

Breeding males of *E. olmstedi* also become very dark but not to so extreme a degree as in *E. nigrum* (Cole, 1957). *E. olmstedi* breeds in a similar manner to *E. nigrum* (Atz, 1940). Males of *E. longimanum* taken in April and June differ from females in having the pigment pattern virtually obscured by melanophores; the fins, the breast, belly, sides, and head are essentially black. The tip of the pelvic fin spine is swollen into a small white bulb. There are fleshy tips to the pectoral fin rays that are most conspicuous on the more ventral fin rays. Males are larger than females (Raney and Lachner, 1943). Males of *E. perlongum* taken on March 26 (CU 30035, Lake Waccamaw) have much darker fins than the females, especially the first dorsal, anal, and pelvic fins. Fleshy tips are present on the distal ends of the pelvic fin elements, but these are not as prominent as in *E. nigrum* or in *E. olmstedi*. Cole (1957) did not find tubercles in any species of the *nigrum* group.

Six collections containing tuberculate males of *E. chlorosomum* have been examined. They were taken between March 8 (TNHC 2374, Texas, San Jacinto Co.) and April 17 (USNM 166172, Texas, Lake Belmont). The best developed male (UMMZ 161309, Louisiana, Lincoln Par., April 7, 39 mm.) has thin, elongated tubercles distributed along the entire length of the ventral surface of the first two pelvic rays, the proximal three-fourths of rays 3 and 4, and the proximal quarter of ray 5. Their presence on the proximal part of the pelvic fin is very unusual; most darters have them best developed distally. A few poorly developed tubercles are scattered on the middle portions of anal rays 2–5 of this specimen. The other tuberculate males show similar patterns, although the tuberculate areas are not as extensive. None of the females are tuberculate. The genital papilla of the female is a swollen rugose pad, differing from that in the *nigrum* group (low and flowerlike) and that in the *stigmaeum* group (an elongate tube). Males of *E. chlorosomum* are darker than females, especially the first dorsal, anal, and pelvic fins, and the venter, but there is no approach to the black fins present in males of the *nigrum* group. Winn (1958b, p. 188) reported Clark Hubbs's observation that *E. chlorosomum* spawns on plants or debris.

Thirteen collections of *E. jessiae* (UMMZ, VPI, CU, USNM) containing tuberculate males were examined. These collections were taken from March 13 (UMMZ 103591, Tennessee, Campbell Co.) to April 10 (UMMZ 103709, 103687, 103676, Tennessee, Anderson Co.). Most males have tubercles only on the ventral scale rows, but at maximum development in March (UMMZ 103567, 114852, 103591) poorly developed tubercles are present on the ventral surface of pelvic rays 3 and 4, and a few are also scattered on the anal fin rays. At maximum development, ventral scale tubercles begin shortly behind the pelvic fin origin on one row of scales and extend onto 4–7 rows per side just anterior to the genital papilla, 2–3 rows above each side of the anal fin base, and a total of 3–4 midventral caudal peduncle scale rows. Males have darker fins and venters than females and have enlarged lateral blotches. The genital papillae of breeding females are thin, elongate tubes totally unlike the genital papillae of breeding females of the *nigrum* group. There is little or no trace of the fleshy tips that develop on the pectoral and pelvic fin rays in the *nigrum* group. In life, breeding males (USNM 187735, Tennessee, Little Pigeon R., April 1) have 8–10 narrow blue bars on the body, the anal fin is blue with a white submarginal band, the dorsals are blue basally with a submarginal red band on the first dorsal and a submarginal white band on the second dorsal. The blue coloration also extends out onto the caudal fin.

The tubercle development of males of *E. stigmaeum* is quite similar to that described above for *E. jessiae*, except that the fin tubercles are better developed (especially in smaller specimens), and there is a puzzling type of geographic variation present. Males of *E. stigmaeum* from Kansas, Kentucky, and Tennessee (UMMZ, USNM) are very similar to males of *E. jessiae* in pigmentation, maximum size of males, and great development of ventral scale tubercles as contrasted with fin tubercles; however, most males from Alabama and Mississippi (UMMZ) are smaller, have less well-developed pigmentation, and have the fin tubercles well developed and the ventral scale tubercles almost absent. This is contrary to most tuberculate darters, which have tubercles better developed in more southern populations. Further study may show subspecific or specific differentiations.

Tubercles are present on males of the northern populations of *E. stigmaeum* from April 6 (UMMZ 165344, Kentucky, E. Fork Barren R.) to April 24 (USNM 163074–5, Kentucky, Green R.). At maximum development (UMMZ 171769, Kansas, Spring R., April 7), ventral scale tubercles start at a point one-third of the distance from the pelvic to the anal fin origin and extend onto three rows of scales per side just anterior to the genital papilla. Tubercles are not present on the scales above the anal fin base or on the ventral surface of the caudal peduncle in any of the males I have examined, but they will probably be found to be present when additional material is examined. One of the three 37 mm. males in this collection shows the best development of anal fin tubercles; they are present on the second anal spine and on all of the soft rays. Pelvic fin tubercles are developed distally to the fork on the ventral surface of pelvic ray 3 and on the entire length of rays 4 and 5. There seems to be a tendency for the fin tubercles to be best developed in smaller specimens and the ventral scale tubercles to be best developed in larger males.

In the southern population of *E. stigmaeum*, fin tubercles but not ventral scale tubercles are present on males from four collections taken from April 2 (UMMZ 155359, Mississippi, Bogue Chitto R.) to May 4 (UMMZ 166388, Alabama, Luxapallila Cr.). A 36 mm. male from UMMZ 155359 has tubercles on the distal three-fourths of all the anal soft rays but none on the spines. A 29 mm. male (UMMZ 163553, Alabama, Big Escambia Cr.) has a few small tubercles on the distal half of the second anal spine. The 36 mm. male has the best developed pelvic fin tubercles on the distal three-fourths of the ventral surface of pelvic soft rays 2–4. Males in one southern collection (USNM 166055, Alabama, Alabama Dr., April 6) have poorly developed pelvic fin tubercles, lack anal fin tubercles, and have ventral scale tubercles starting one-third of the way posteriorly from the pelvic to the anal fin origin and extending onto 3 rows of scales just anterior to the genital papilla, 0–2 rows above each side of the anal fin base, and onto 3 ventral caudal peduncle scale rows. This collection matches the description of the northern populations of *E. stigmaeum* more closely than the southern ones.

In studying the breeding behavior of Kentucky and Tennessee populations of *E. stigmaeum*, Winn (1958b, p. 172) found that males are larger than females and have larger anal and pelvic fins. He reported the presence of tubercles on the anal and pelvic fins of males but failed to find any on the ventral body scales. Cross and Minckley (1958) described the coloration of breeding males and noted tubercles on the anal fin rays. In spawning, the male mounts the female in such a manner that his tuberculate pelvic fins are in contact with her dorsum and his tuberculate anal fin and ventral scales are in contact with her sides (Winn, 1958a; 1958b, fig. 4). This spawning position is similar to that found in a number of other darters such as *E.* (*Oligocephalus*) *caeruleum* and *E.* (*O.*) *spectabile* and is totally unlike the complex inverted spawning position of the *nigrum* species group of *Boleosoma*. Winn (1958b, p. 188) felt that the placement of *stigmaeum* in *Boleosoma* should be reconsidered.

### Subgenus *Ioa* Jordan and Evermann

The only known species is *E. vitreum* (Cope). Specimens taken from March 28 to May 17 (CU, UMMZ) lack tubercles. The males are larger than the females and become much darker in the breeding season, especially on the cheeks and venter. The genital papilla of the breeding female has many free fleshy villi. Winn and Picciolo (1960) noted the pigment differences between the sexes and did not mention the presence of breeding tubercles. They reported that *E. vitreum* spawns communally in mid-April on a solid surface in the path of a strong current. This behavior may have evolved from spawning under rocks practiced by some members of the subgenus *Boleosoma*. Winn and Picciolo listed several similarities between *E. vitreum* and *E. nigrum* in support of this hypothesis: the sexes are beside each other during spawning; one egg is laid at a time on a hard surface; males are very black in the breeding season; and females of both species have a complicated flowerlike genital papilla. The lack of breeding tubercles in *Ioa* and the *E.* (*Boleosoma*) *nigrum* species group further confirms this relationship.

### Subgenus *Etheostoma* Rafinesque

Fifteen species are presently placed in this subgenus. The subgenus can be divided into two different tuberculate species groups and one nontuberculate group. Members of the *variatum* group, *variatum*

Kirtland, *tetrazonum* (Hubbs and Black), *euzonum* (Hubbs and Black), *kanawhae* (Raney), and *osburni* (Hubbs and Trautman) have breeding tubercles on the ventral scales in both sexes. This appears to be the only group of darters with both sexes tuberculate. (In the Romanichthyini, both sexes of *Zingel* and *Romanichthys* are tuberculate.) Species of the *variatum* group are heavy-bodied darters with prominent dorsal saddles. Breeding males of many of the species have bright colors. Species of the *inscriptum* group, *inscriptum* (Jordan and Brayton), *thalassinum* (Jordan and Brayton), *swannanoa* Jordan and Evermann, *blennioides* Rafinesque, and *gutselli* (Hildebrand), have similar but less prominent tubercles present only on the males. The tubercles in both groups, unlike the more conical ones present in most other percids, are low whitened pads on the free posterior edges of the ventral and lateral scales. The nontuberculate *zonale* group includes *zonale* (Cope), *rupestre* Gilbert and Swain, *histrio* Jordan and Gilbert, and probably *blennius* Gilbert and Swain. *E. sellare* (Radcliffe and Welsh) is apparently also nontuberculate, but it does not seem to be related closely to any of the three species groups.

Breeding tubercles are present on *E. variatum* from as early as October 5 (USNM 161783, Pennsylvania, Allegheny R.) until May 12 (CU 43070, New York, Allegheny R.). No tubercles are present on Allegheny River specimens taken in June or August. The October 5 collection has 27 females and 18 males (57–70 mm. in standard length) without tubercles and 8 males (60–66 mm.) with small tubercles on 2 rows of midventral scales per side just anterior to the genital papilla and on 4 rows on the midventral portion of the caudal peduncle. Four females (58–67 mm.) taken October 13 (USNM 161786) also lack tubercles while a 74 mm. male has small tubercles on 4 ventral scale rows per side just anterior to the genital papilla and on 4 midventral rows on the caudal peduncle. By April 19 (CU 34938) tubercles are present on 5 rows of ventral scales per side just anterior to the genital papilla. Females taken April 20 (CU 8226, fig. 5) have tubercles on about 6 rows of belly scales per side just anterior to the genital papilla. William J. Richards kindly called my attention to a male taken April 29 (CU 41893, New York, Allegheny R.) that has tubercles on the approximately 20 breast scales, on all the belly scales up to 6 rows per side just anterior to the genital papilla, 4–5 rows above the anal fin base, and 7 midventral scale rows on the caudal peduncle. Both May 12 males (CU 43070, 69–70 mm.) have tubercles extending onto 7 rows per side just anterior to the genital papilla. These males and CU 41893 also have tubercles on the ventralmost 2 rows of scales which extend onto the lower part of the caudal fin. The presence of breeding tubercles in *E. variatum* has not previously been reported although tubercles are plainly visible in a photograph of a breeding male (Hubbs and Black, 1940, pl. 2, fig. 1). The tips of the pelvic elements are more swollen in males in CU 8226 than in females. The genital papillae of females are elongate tubes. The pelvic and anal fins of females are only slightly pigmented while those of breeding males are completely black, except for white fleshy tips on the anterior elements in both fins. The pectoral fins of females are banded, while in breeding males they are completely black. The breast and belly of females are nearly immaculate, while those of males are completely covered with melanophores. Both dorsal fins of males are more heavily pigmented than those of females. Lachner, Westlake, and Handwerk (1950) reported that males of *E. variatum* were larger, brighter, and more highly pigmented, and that they had larger pelvic and dorsal fins than females.

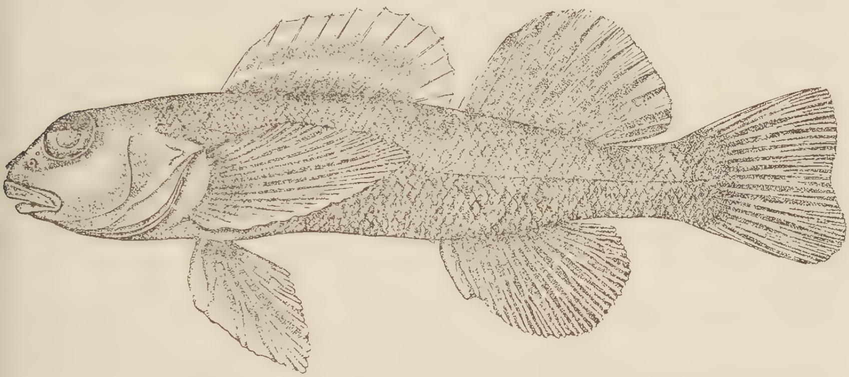

FIGURE 5.—Male of *Etheostoma* (*Etheostoma*) *variatum* showing the distribution of breeding tubercles (CU 8226, Pennsylvania, Shenango River, April 20, 72 mm. SL).

Males of *E. tetrazonum* taken in Missouri March 16 to April 6 (CU 32879, 37380, 37354; KU 7537) have tubercles on all the breast scales, on 3–5 rows of scales per side just anterior to the genital papilla; 1 row above the anal fin; and a total of 7 ventral caudal peduncle rows. The tubercles are best developed on the largest males but are obvious on other males down to 47 mm. standard length. Females have lower and much less prominent tubercles on 6 rows of midventral scales. Males are much darker than females, with the second dorsal, pelvic, and anal fins almost black. Bands on the pectoral, second dorsal, and caudal fins of females are completely obscured by dark pigment in males. The head, breast, and belly of males are also much darker than in females.

Tubercles are present on *E. euzonum* taken April 4 (CU 32900, Missouri, White R.), April 7 (KU 7634, Missouri, Current R.), and April 30 (TU 10175, Arkansas, White R.). In males they are present on the breast scales, on about 7 scale rows per side just anterior to the genital papilla, 3 rows above the anal fin base, and 6-7 rows of ventral scales on the caudal peduncle. Females have a similar tubercle distribution, but the tubercles are smaller and do not extend as far dorsally. Tubercles are absent in specimens (UMMZ) taken in July and August.

The same tubercle distribution is present on specimens of *E. kanawhae* taken from April 1 (UMMZ 131838, North Carolina, New R.) to June 8 (USNM 162196 and 162197, Virginia, New R.). Males with maximum tubercle development (USNM 162197) have tubercles on 2 rows of scales at the pelvic fins extending onto 7 rows of scales per side just anterior to the genital papilla, 4 rows above each side of the anal fin base, and a total of 8 rows on the ventral caudal peduncle scales. The maximum development of tubercles observed in females is on a 66 mm. specimen from the same collection. Here tubercles also begin at the pelvic fins and extend onto 7 rows of scales just anterior to the genital papilla, but are present on only 2 rows of scales above each side of the anal fin base and on only 5 rows of caudal peduncle scales. Small tubercles are present on three males taken July 23 (UMMZ 165448, North Carolina, Little R., 57–66 mm.), but they are absent from a 61 mm. female from the same collection. Faint traces of tubercles are barely discernible on males taken as late as August 24 (UMMZ 169360, Virginia, Little Reed Island Cr.). In the original description of *E. kanawhae*, Raney (1941) mentioned that the holotype, as well as other males taken near the breeding season, had the scales on the belly and lower sides "tipped with pearl white." Tubercles are clearly visible in his photograph of a male paratype.

Tubercles are present on specimens of *E. osburni* taken between May 17 (USNM 117588, paratype; and UMMZ 95370, Virginia, Reed Cr.) and July 15 (UMMZ 118800, West Virginia, Indian Cr.); they are absent from specimens taken in August and October. At maximum development males have tubercles on 5–7 rows of midventral scales per side just anterior to the genital papilla, 3–5 rows above each side of the anal fin base, and on 4–8 rows on the caudal peduncle. Some of these tubercles have points on their posterior ends. Females have a similar distribution of tubercles, but they are lower, broader, and lack the points present on males. Males are darker than females, especially the pelvic, anal, and second dorsal fins, and the head. In their original description of *E. osburni*, Hubbs and Trautman (1932) did not mention the presence of breeding tubercles, but they can be seen in their figure of the holotype (UMMZ 92409). They are also present on a paratype (USNM 117588).

Thus the intimate relationships of the five species in the *variatum* group as noted by Hubbs and Black (1940) and Raney (1941) are further corroborated by similarities in the distribution of breeding tubercles. With reservations, Hubbs and Black included *E. blennius* in their *variatum* group; I would tentatively remove it since it appears to be nontuberculate. They considered the possibility that *E. sellare* might belong to the *variatum* group; I feel this is highly unlikely.

Tubercle distribution in the *inscriptum* group is similar to that in the *variatum* group, but the tubercles are not on as many areas nor are they present in females. Tubercles are present on males of *E. inscriptum* in the Savannah Drainage at least from March 25 (CU 19548, 19755) until June 3 (CU 37935). At maximum development (USNM 165732, Georgia, Altamaha Dr., April 5), tubercles start one-fourth of the way posteriorly from the pelvic fin origin to the anal origin and extend onto 4 rows of scales per side just anterior to the genital papilla, 3 rows above the anal fin base and 5 ventral caudal peduncle rows. Males are much darker than females, especially the dorsal, anal, and pelvic fins, and the breast and the belly. There are two concentrations of pigment on the membranes of the first dorsal fin of males, anteriorly between the first 3 spines and posteriorly between the last 2 spines. The tips of the pelvic spine and, to a lesser extent, the lower pelvic rays are swollen in males. The general banded pattern of females is obscured by the increased body pigmentation of breeding males. The genital papilla of the breeding female is a very long thin tube.

*E. thalassinum* from the Santee Drainage of North and South Carolina has virtually the same tubercle pattern as *E. inscriptum*. Tubercles are present at least during the period March 23 (USNM 187567, 187580; CU 10113, 19662; UMMZ 138494) until April 20 (USNM 187578, 187582). Four females collected on February 27 (USNM 187576) are filled with large eggs and I believe males are probably tuberculate at this time. The maximum development of tubercles observed is on a 57 mm. male taken on April 19 (USNM 187573). Tubercles start posteriorly one-fourth of the way from the pelvic fin origin to the anal origin and extend onto 4 rows of scales per side just anterior to the genital papilla, 3 rows above the anal fin base, and a total of 5 ventral caudal peduncle rows. Tubercles are less well developed in the earlier part of April. Tubercles are absent from males taken June 25 to November 6. All females lack tubercles. Males are darker than females, especially the pelvic and anal fins, which in females are immaculate.

Males of *E. swannanoa* taken between April 1 (UMMZ 138521, Virginia, Holston R.) and June 7 (CU 37886, North Carolina, French Broad R.) have tubercles on the ventral scales. At maximum development (UMMZ 138482, North Carolina, Swannanoa R.), the tubercles begin one-third of the way posteriorly from the pelvic fins to the origin of the anal fin and extend onto 4–5 rows of scales per side just anterior to the genital papilla, 3–4 rows above each side of the anal fin base, and 5 rows of ventral scales on the caudal peduncle. Specimens collected from June 17 to August 15 (UMMZ) lack tubercles. Females also lack tubercles. Females of *E. swannanoa* have the longest genital papillae in relation to body size that I have found in any darters. A 61.4 mm. female had a genital papilla 5.9 mm. long.

I have examined four collections containing tuberculate males of *E. blennioides.* In addition, Dr. Robert V. Miller, who is presently reviewing the taxonomy of this species, has kindly provided me with his notes on tubercles and called my attention to two collections containing tuberculate specimens. Tubercles are present on males of *E. blennioides* at least as early as March 24 (CU 37520, Kentucky, Licking R.) until June 26 (UMMZ 96357, Tennessee, Cumberland R.). At maximum tubercle development (CU 20629, Pennsylvania, Genesee R., April 27), tubercles start a third to halfway posteriorly from the pelvic fin origin to the anal fin, extend onto 4–6 rows per side just anterior to the genital papilla, 1–3 rows above each side of the anal fin base, about 5–6 rows of ventral caudal peduncle scales, and are found also on some of the small scales at the ventral part of the base of the caudal fin. By June 26 (UMMZ 96357), tubercles have almost disappeared. Spawning occurs in New York between April 13 and June 12 (Fahy, 1954, p. 167), so there is a good correlation with the presence of tubercles. Tubercles are absent on females. Winn (1958b, p. 172) and Lachner, Westlake, and Handwerk (1950) reported that males were larger than females and had larger first dorsal and anal fins. Winn also reported that males had larger pectoral and pelvic fins. Lachner et al. found the pelvic fins of both sexes to be of about equal size, the second dorsal fin larger and the pectoral fin smaller in males. The tips of the pelvic spines and most of the soft rays are slightly more swollen in breeding males than in breeding females. Males are much darker, especially the head, venter, and body, and the pelvic and anal fins.

*E. blennioides* spawns at a horizontal to a vertical angle, usually at about 45° (Winn, 1958a; 1958b). Spawning takes place over *Cladophora*-covered rocks in the deepest and swiftest parts of stream riffles (Fahy, 1954, p. 169). The male mounts the females with his pelvic fins over her dorsum and his tuberculate lower sides in contact with her sides (Winn, 1958a; 1958b, fig. 4).

In his studies on *E. gutselli,* Miller has found only two tuberculate specimens, which he has generously permitted me to examine. Both are males, 87 and 91 mm. long, taken in the northeastern corner of Georgia May 9 (UG uncat.). Small, low tubercles begin halfway posteriorly from the pelvic fins to the anal fin origin and extend onto

4 rows of scales per side just anterior to the genital papilla. A few tubercles are present on the scales above the origin of the anal fin base, but they are absent posteriorly. Miller has not found tubercles on any females of this species. Males are very dark with the lateral markings almost obscured. The tubercle and pigment patterns of *E. gutselli* confirm its close relationship to *E. blennioides.*

Four of the five remaining species currently placed in the subgenus *Etheostoma* can be assigned to the nontuberculate *zonale* group. These are *rupestre, zonale, histrio,* and probably *blennius.* Proper allocation of the fifth species, *E. sellare,* is difficult at present. Hubbs and Black (1940) considered that it might belong to the *variatum* group because of its bold back markings. However, the two types of *E. sellare* are both spring-caught females and lack tubercles, rendering this unlikely. I do not feel that it is closely related to any of the three species groups of the subgenus *Etheostoma,* but I cannot suggest a better group to place it in.

Specimens of *E. rupestre* taken in April and May (USNM 166029 and UMMZ 166372, Alabama, Tombigbee R.; TU 19896 and UMMZ 171762, Alabama, Cahaba R.) lack tubercles. Both males and females have the tips of the pelvic spines and most of the soft rays tipped with cream-colored fleshy knobs. Females have the anal and pelvic fins and the breast and belly immaculate, whereas males have these areas and the dorsal fins very dark. The testes and ovaries of these specimens are greatly enlarged. Specimens of *E. zonale* in 16 collections (USNM, UMMZ) taken from March 1 (TU 8170, Mississippi, Pearl R.) to June 21 (UM 5219A) lack tubercles. The pigmentation differences between the sexes are very similar to those in *E. rupestre.* Lachner, Westlake, and Handwerk (1950) reported that males of *E. zonale* were larger than females and had larger dorsal fins. Specimens of *E. histrio* in August, October, and January collections (USNM, UMMZ) and in a March 25 Texas collection (TNHC 1114) are nontuberculate. Males of *E. histrio* taken in January and March have greatly enlarged testes and the females are filled with large eggs. Spring caught specimens of *E. blennius* (UMMZ) lack tubercles, but sufficient material has not yet been examined to be sure this species belongs to the *zonale* group.

### Subgenus *Ulocentra* Jordan

There are four described species: *atripinne* (Jordan), *coosae* (Fowler), *duryi* Henshall, and *simoterum* (Cope), plus about nine undescribed species, in this subgenus (R. M. Bailey, pers. comm.). I have examined some breeding material of all described species as well as a number of the manuscript forms (mostly UMMZ specimens). Males of all species are brightly colored in life and apparently lack breeding tubercles. In the absence of tubercles, as well as in other characters, the subgenus *Ulocentra* seems most closely related to the *Etheostoma* (*Etheostoma*) *zonale* species group.

Winn (1958b, p. 172) noted that males of two of the undescribed forms of *Ulocentra* (from the Barren and Green rivers of Kentucky) were larger than the females, had larger anal, first dorsal, and pelvic fins, and lacked breeding tubercles. These two species usually spawn in a nearly vertical position with the male mounted on the female's back (Winn, 1958a; 1958b, fig. 4).

### Subgenus *Allohistium* Bailey

There is only a single species: *E. cinereum* Storer. The testes and pigmentation of a spring-caught male (CU 37281, Tennessee, Cumberland R., March 26, 56 mm.) are well developed and breeding tubercles are absent. Males in six collections taken later in the year (ANSP, UMMZ, USNM) have slightly developed testes and also lack tubercles.

### Subgenus *Nothonotus* Agassiz

There are seven described species in this subgenus: *acuticeps* Bailey, *camurum* (Cope), *jordani* Gilbert, *maculatum* Kirtland, *moorei* Raney and Suttkus, *rufilineatum* (Cope), and *tippecanoe* Jordan and Evermann. Apparently this subgenus lacks breeding tubercles, although I have not examined adequate breeding material of *acuticeps* or *tippecanoe*.

Bailey (1959) described the sexual dimorphism in color as well marked in *Nothonotus*. He wrote (p. 3): "All species are colorful, varying from subdued to gaudy. The breast is blue or green in adult males . . . . The body is lined with dark in several species; the soft dorsal, caudal, and anal fins are dark-edged in some, and the fins may be somber or brightly colored with red, orange, or green . . . . No species has a submarginal red or orange band in this [first dorsal] fin." For *E. acuticeps*, he reported (p. 8): "It is probable that no nuptial tubercles are developed since adults taken in June, and nearly ready to spawn, have none." Raney and Suttkus (1964) reported that nuptial tubercles are absent in *E. moorei*. Raney and Lachner (1939) noted that males of *E. maculatum* attain a larger size than females. In addition, Winn (1958b, p. 172) reported that males have larger anal, first and second dorsal, pectoral, and pelvic fins than females. He described the genital papilla of the breeding female as flattened and flowerlike, and he did not find breeding tubercles on the male. *E. maculatum* spawns under rocks and the male defends the nest (Raney and Lachner, 1939). *E. camurum* spawns in gravel around or under rocks in a spawning position similar to that described by Winn (1958b, fig. 4) for *E. caeruleum* (Mount, 1959).

### Subgenus *Oligocephalus* Girard

Twenty-one species are presently placed in this, the largest subgenus of *Etheostoma*. There appear to be three different tuberculate species groups and one nontuberculate group. Males of the *nianguae* group, *nianguae* Gilbert and Meek and *sagitta* (Jordan and Swain), have conical tubercles on the ventral scales. Males of the *radiosum* group, *radiosum* (Hubbs and Black), *whipplii* (Girard), and *caeruleum* (Storer) have tubercles that are similar to but not as high as those in the *E. nianguae* group. Eight other tuberculate species may best be placed together for the present, although they differ from one another in the details of tubercle distribution: *punctulatum* (Agassiz), *fricksium* Hildebrand, *hopkinsi* (Fowler), *parvipinne* Gilbert and Swain, *spectabile* (Agassiz), *luteovinctum* Gilbert and Swain, *pallididorsum* Distler and Metcalf, and *cragini* Gilbert. The species in the *spectabile* group differ from the two previous groups in having tubercles on the anal fin. Two of the species in this group have tubercles on only the anal fin, while the others also have them in additional regions. This leaves a residue of eight species which appear to be nontuberculate: *asprigene* (Forbes), *swaini* (Jordan), *mariae* (Fowler), *juliae* Meek, *pottsii* (Girard), *lepidum* (Baird and Girard), *exile* (Girard), and *grahami* (Girard).

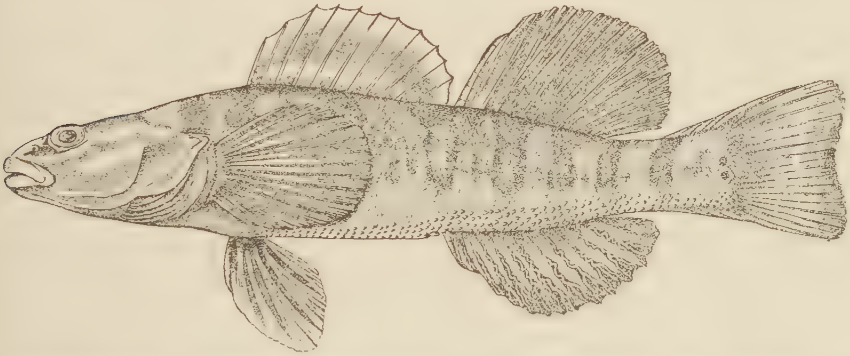

FIGURE 6.—Male of *Etheostoma* (*Oligocephalus*) *nianguae* showing the distribution of breeding tubercles (CU 32888, Missouri, Osage River, March 16, 89 mm. SL).

A fine breeding male of *E. nianguae* (CU 32888, Missouri, Miller Co., Big Tavern Cr., Mar. 16, 1957, a specimen overlooked by Kuehne and Bailey, 1961) has breeding tubercles well developed on about 12 mid-ventral scale rows just anterior to the genital papilla (fig. 6). There are no tubercles on either the pelvic or anal fins. There is, however, a sinuous ridge of fleshy material extending along each element of the anal fin. A 51 mm. male of *E. sagitta sagitta* (USNM 144485, Kentucky, Cumberland R., April 8) has tubercles on the ventral scales beginning halfway posteriorly from the pelvic to the anal fin and extending onto 3–4 rows of scales per side just anterior to the genital papilla. The tubercles are high and conical. None are present above the anal base or on the lower surface of the caudal peduncle. However, a larger specimen from the same field collection (UMMZ 144492) has tubercles on 2 rows of scales above each side of the anal fin base and on 5–6 midventral rows on the caudal peduncle, as Bailey (1948) has previously noted. I have not yet examined a tuberculate specimen of *E. sagitta spilotum* Gilbert. The similarity of breeding tubercle distributions further confirms the intimate relationships of *E. nianguae* and *E. sagitta* as pointed out by Bailey (1948, in describing the subgenus *Litocara* for the three forms), and Kuehne and Bailey (1961).

There are tubercles on the ventral scales of males of *E. radiosum* in nine collections taken between April 4 and April 25 in the Red River drainage of Oklahoma and Arkansas: USNM 165772, 165797, 165865, 165866; UMMZ 161368 holotype, UMMZ 161369, and MCZ 37205 paratypes of *E. radiosum paludosum* (Moore and Rigney); USNM 153532 and MCZ 37204, paratypes of *E. radiosum cyanorum* (Moore and Rigney). A 52 mm. male from USNM 153532 has the best developed tubercles, located on 3 rows of ventral scales starting about one-fourth of the way from the pelvic origin to the anal origin. They are slightly raised, circular mounds on the posterior edge of the scales, not pads as in the *variatum* group. The tubercles on the ventralmost scales have elongate points on their posterior end. Just anterior to the genital papilla, tubercles are present on about 6 scale rows per side. They are on 5 rows of scales above each side of the anal fin base and on 7 midventral rows of scales on the caudal peduncle. The tubercle patterns are similar in the larger males in the other collections, but the tubercles are smaller and are not developed on as many scale rows. None of the more than 120 females in these collections show any sign of tubercle development and all the larger females have the ovaries filled with large eggs. The genital papilla of the female is an elongate cone. The pelvic fin and venter of the female are immaculate, the anal fin is moderately pigmented, and the dorsal fins are somewhat blotched and banded. In the male, the pelvic fin and venter are very dark, the dorsals, anal, and caudal fin are heavily pigmented on the basal half and have a light (orange in life) strip followed by a dark distal edge to the fin. In their original description of *E. radiosum paludosum,* Moore and Rigney (1952) reported tubercles on the bellies of males. In spawning, the female *E. radiosum cyanorum* partially buries herself in sand

and the male mounts her with his pelvic fins clasped over her dorsum and his tail pressed tightly against hers (Linder, 1958).

The same tubercle pattern was found on males of *E. whipplii* taken between February 29 (UMMZ 177250, Arkansas, Illinois Bayou) and April 12 (TU 17771, Texas, Neches R.). At the maximum development observed (UMMZ 155103, Kansas, Crooked Cr., April 9; and UMMZ 177160, Arkansas, Illinois Bayou, April 3), tubercles begin one-third of the way from the pelvic fin origin to the anal fin origin, extend onto 5–7 rows of scales per side just anterior to the genital papilla, on 2–3 rows above each side of the anal fin base, and onto 6–8 midventral rows of caudal peduncle scales. Specimens taken earlier (UMMZ 177250, February 29) and later (TU 17771, April 12) lack tubercles above the anal fin base and on the ventral surface of the caudal peduncle.

The tubercle pattern of *E. caeruleum* seems to be the same as that of *E. radiosum* and *E. whipplii*. Leslie W. Knapp, who is reviewing the systematics of *E. caeruleum*, has kindly given me his data on tubercles of this species and has permitted me to examine the specimens with the best developed tubercles. Poorly developed tubercles are present in 15 collections taken in Missouri and Arkansas between March 27 (CU 37190, Missouri, Madison Co.) and June 5 (KU 5605, Missouri, Gasconade R.). Males from an Illinois collection (INHS uncat., Rock R., April 25) are at the height of breeding color according to Knapp and show the best development of tubercles. A 51 mm. male from this collection has tubercles present on the belly scales starting halfway from the pelvic to the anal fin origin and extending onto 4 rows of scales per side just anterior to the genital papilla, on 2–3 rows above the anal base, and on about 5 midventral rows on the caudal peduncle. There are no tubercles on the fins of these or many other breeding males examined. Winn (1958b, p. 172) reported that males of *E. caeruleum* are larger than females and have larger anal, first dorsal, pectoral, and pelvic fins, but he failed to find breeding tubercles. In spawning, the female of *E. caeruleum* partially buries herself in the gravel of the stream bottom and the male mounts her (Winn, 1958a; 1958b, fig. 4). Since the belly and sides of the male are then in contact with the sides of the female, the tubercles may assist him in maintaining his position.

Temporarily, at least, the other eight tuberculate species of the subgenus *Oligocephalus* may be placed together in the *spectabile* group based on the presence of breeding tubercles on the anal fin of males. *Etheostoma parvipinne* and *E. fricksium* have tubercles on the anal fin alone. The other six species, *hopkinsi*, *cragini*, *punctulatum*, *luteovinctum*, *pallididorsum*, and *spectabile*, have tubercles in other areas as well. Females of all six species lack tubercles.

Numerous males of *E. parvipinne* taken early in 1952 in a tributary of the Yazoo River, Mississippi, have tubercles on the anal rays. A 55 mm. male taken February 22 (USNM 196636), has tubercles on the distal fourth of the first anal soft ray, the distal half of the second ray, the distal half to two-thirds of rays 3–5, and the distal third of rays 6–7. There are no tubercles on the anal spine or the last anal soft ray. Males taken later in the spring (exact dates unknown) have similar tubercle distributions, but the tubercles are larger and extend farther proximally on the rays. (Some specimens from the original collections, UM 47 and 521A, have been recatalogued as USNM 196636, 196637, UMMZ 162907.) Two 44 mm. males taken March 7 (TNHC 2835, Texas, Montgomery Co.) have tubercles developed on the distal half to three-fourths of all anal soft rays. There are no pelvic or body tubercles on any of the specimens. The belly and pelvic fins of the females are immaculate. These areas, plus the anal and dorsal fins, are dark in the males. Males taken from April 4 to April 22 (UMMZ) lack tubercles.

Bailey and Richards (1963) stated that breeding tubercles are present on the lower surface of the pelvic fin, anal fin, and on the ventral body scales of breeding males of *E. hopkinsi.* Richards has very kindly called my attention to the only tuberculate specimens he has examined. Males of *E. hopkinsi binotatum* Bailey and Richards are tuberculate from as early as March 25 (CU 19604, S.C.) until April 29 (UG 283, Georgia) in the Savannah River drainage. The maximum development of tubercles is on a 39 mm. male collected March 27 (CU 19600, South Carolina, Savannah Dr.). A few tubercles are present on the distal tip of the second anal spine and 5–10 prominent tubercles are present on all the anal soft rays except the last half of the last ray. Small but prominent tubercles are developed on the ventral surface of the proximal portion of pelvic soft rays 3–5. Tubercles (and scales) begin halfway posteriorly from the pelvic fins to the origin of the anal fin and extend onto 3–4 rows of scales per side just anterior to the genital papilla. No tubercles are present above the anal fin base or on the ventral surface of the caudal peduncle.

Dr. Richards has also permitted me to examine the tuberculate specimens he has found of *E. fricksium.* A few very small tubercles are on anal soft rays 3–6 of two males (CU 17375, Georgia, Savannah Dr., 46–50 mm.) taken March 24. Tubercles are also present on the anal rays of males taken in the Edisto drainage (CU 29850, South Carolina, March 28). Additional tuberculate specimens are needed to determine whether tubercles develop on the pelvic fins and venter of *E. fricksium* as they do on *E. hopkinsi.* If not, tubercle pattern will be one additional difference between the two species which had been confused until recently (Bailey and Richards, 1963).

Tubercles were found on males of *E. cragini* collected from January 1 (UMMZ 156694, Kansas, Meade Co.) to May 7 (KU 5658, Missouri, Shoal Cr.). Tubercles are best developed on two males from UMMZ 156694 (30 and 31 mm.), on the 50 mm. male syntype of the nominal species *E. pagei* Meek (USNM 45566, Missouri, Neosho R., Apr. 15, 1893), and on a specimen collected April 5 (CU 32919, Missouri, Neosho R., 32 mm.). In the latter specimen, tubercles are present on most of the length of the anal spines and soft rays, on the distal two-thirds of the pelvic spine, and the distal third of the first three pelvic soft rays (ventral surface). No tubercles are present on the dorsal surface of the pelvic rays in this specimen, but there are a few tubercles on the distal tip of pelvic rays 1 and 2 in KU 7233. On the CU specimen, tubercles also are present on the ventral scales starting posteriorly one-third of the distance from the pelvic to the anal fin origin. They extend onto about 5 rows of scales per side just anterior to the genital papilla and onto 2–3 rows above each side of the anal fin base. No tubercles are present elsewhere on these specimens nor are they present on the females. Tubercles are absent from the abundant UMMZ material of *E. cragini* collected in June, July, and August. Moore and Cross (1950) reported tubercles on the anal rays of males of *E. cragini* taken January 1 (UMMZ 156694). They also found tubercles on the pelvic fins, the ventral scale rows near the anal base, and along the belly of breeding males taken February 2 in Mayes Co., Oklahoma.

A similar tubercle distribution is present on some of the paratypes of the closely related *Etheostoma pallididorsum*. Nine males collected April 6 (KU 6158, Arkansas, Caddo R.) are tuberculate. All have tubercles along both anal spines and on all the anal soft rays. Pelvic fin tubercles are poorly developed on the 5 smaller specimens (29, 31, 33, 34, and 35 mm.), better developed on two larger specimens (35 mm.), and best developed on the two largest specimens (37 mm.). Here they are present on the distal three-fourths of the pelvic spine and first pelvic soft ray (dorsal and ventral surfaces), the distal three-fourths of ray 2 (ventral surface), and distal half of ray 2 (dorsal surface), the distal third of ray 3, and the distal quarter of ray 4 (ventral surface only). The ventral scale tubercles are best developed on a 35 mm. male where they begin halfway between the pelvic and the anal fins, extend onto 4 rows of scales per side just anterior to the genital papilla, 2 rows above each side of the anal fin base, and are present on the ventral surface of the caudal peduncle. Tubercles are absent in another collection of paratypes (USNM 196547) taken June 28. The identical tubercle distributions in *E. pallididorsum* and *E. cragini* serve as further evidence of their very close relationship. In their original description, Distler and Metcalf (1962) reported tubercles on the anal fin rays and on the belly scales of the paratypes described above.

Males of *E. punctulatum* in seven collections (UMMZ, KU, CU, TU) taken from January 30 (TU 22993, Oklahoma, Neosho R.) to May 2 (TU 2251, Oklahoma, Arkansas R.) have tubercles. They are present on the anal spines and soft rays of males taken in this period but are best developed on the soft rays. A 54 mm. male (CU 37346, Missouri, Osage R.) taken March 28 has the maximum tubercle development observed. There are 15–20 tubercles on each anal soft ray, fewer on the anal spines. Tubercles are present on the ventral surfaces of all pelvic fin elements, ranging in number from 5 (on the spine) to 30 (on the second soft ray). Tubercles are present on the dorsal surfaces of pelvic soft rays 1–3 as well as on the ventral surfaces. Tubercles are also present on about 7 rows of the ventral scales per side just anterior to the genital papilla and on about 6 rows along each side of the anal fin base. There are a few small tubercles on the ventralmost principal caudal ray.

Males of *E. luteovinctum* are tuberculate from at least March 26 (CU 37235) until April 28 (UMMZ 121612) in Duck River, Tennessee. Tubercles develop earliest and remain for the longest period of time on the anal fin. Except for tubercles on the anal spines, the males in CU 37235 have the best developed tubercles of the specimens examined. No tubercles are present on the first anal spine, a few are present on the second anal spine, and there are 5–10 tubercles on each of the anal soft rays. There are no tubercles on the ventral surfaces of the pelvic fin elements, but four intermediate-sized specimens have several tubercles distally on the dorsal surface on soft rays 1 and 2. Ventral tubercles start halfway from the pelvic to the anal fin and extend onto 4–5 scale rows per side just anterior to the genital papilla, 3 rows along each side of the anal base, and 5 midventral rows on the caudal peduncle. A few tubercles are present on the ventralmost principal caudal ray in the largest specimen. No tubercles are present on the pectoral fin. Some males (UMMZ 120985) have tubercles on the first instead of the second anal spine. Others (UMMZ 121259) have tubercles on both anal spines, although the tubercles are not as well developed in the other regions as in CU 37235. The nine collections with tuberculate males contained no tuberculate females.

Tubercles are present on the anal, pelvic, pectoral, and caudal fins and on the ventral scales of the males of *E. spectabile*. I have found tubercles on males of *E. s. spectabile* taken in late March (CU 37240, Missouri, Osage R.; CU 37496, Tennessee, Barren R.; CU 37436, Arkansas, White R.) and in early April (CU 38406, Missouri, Osage R.). Tubercles are present on 61 males (26–42 mm. standard length) of *E. spectabile pulchellum* (Girard) taken April 20 (USNM 165807, Oklahoma, Poteau R.). At their maximum development, tubercles are present along the entire length of the anal fin elements and on the ventral surfaces of all the pelvic soft rays. Tubercles are also developed on the dorsal surfaces of pelvic soft rays 1–3 and on the anterior surfaces of pectoral rays 6–8. There are tubercles on about 4 rows of ventral scales per side just anterior to the genital papilla, on 4–5 rows above the anal fin base, and on 8 midventral rows on the caudal peduncle. A few males (CU 37436, fig. 7) have scattered small tubercles on the lower caudal rays. Males of *E. spectabile* are much darker than females, especially the pelvic, anal, dorsal, pectoral, and caudal fins, and on the breast and belly. The tips of the pelvic fin spine and, to a lesser extent, the pelvic and lower pectoral fin rays, have slightly swollen, unpigmented tips. Winn (1958b, p. 172) reported that males of *E. s. spectabile* were larger than females and had larger anal, first dorsal, pectoral, and pelvic fins, but he found no tubercles. In spawning, the male mounts the female after she has buried herself in the gravel of the bottom of the stream bed (Winn, 1958a; 1958b, fig. 4; Linder, 1958). The tuberculate pelvic fins of the male are in contact with the female's back; and his belly, sides, and caudal peduncle are pressed against hers.

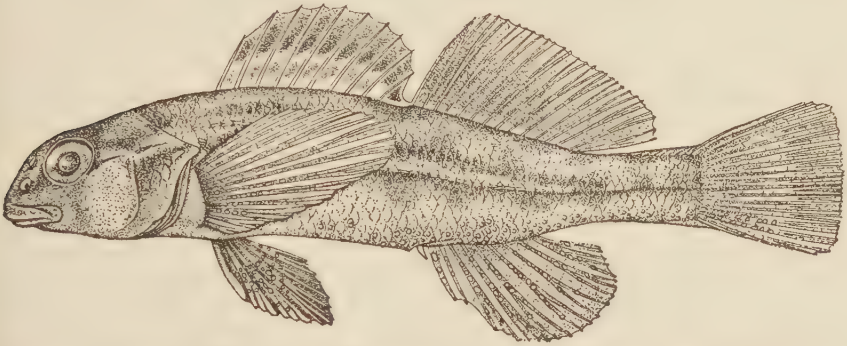

FIGURE 7.—Male of *Etheostoma* (*Oligocephalus*) *spectabile* showing the distribution of breeding tubercles (CU 37346, Arkansas, White River, March 29, 44 mm. SL).

The residual, apparently nontuberculate group of eight species of *Oligocephalus* (*asprigene, exile, grahami, juliae, lepidum, mariae, pottsii* and *swaini*) probably are not closely related to each other. Certainly they are quite diverse in general body form and pigmentation. The following list of numbers and sources of collections with included dates shows the relative adequacy of coverage of the species in this group: *asprigene*, 6 collections, Nov. 21 to June 16 (CU, USNM, TU, UMMZ); *exile*, 6 collections, May 14 to August 26 (UMMZ); *grahami*

(UMMZ 162135, Mexico, Nuevo Leon, Dec. 19, 14 males, 27–36 mm., and 35 females; TNHC 1971, Texas, Val Verde Co., April 14, 10 males, 29–40, mm., and 14 females; testes of males in both collections greatly enlarged and females filled with large eggs); *juliae*, 11 collections, Oct. 25 to Aug. 22 (TU, CU, UMMZ); *lepidum*, 6 collections, Feb. 4 to June 25 (CU, UMMZ, USNM); *mariae*, 5 collections, April 1 to June 29 (CU, UMMZ, TU, USNM); *pottsii* (USNM 162482, Feb. 14; USNM 55855, no date; TNHC 4032, June 26; testes enlarged in males, females filled with large eggs); and *swaini*, 5 collections, Jan. 28 to April 4 (TU, CU, UMMZ). Winn (1958b) found that females of *E. exile* are larger than males. Males have larger anal and first dorsal fins and lack breeding tubercles. Spawning takes place at a slight angle over organic debris and fibrous mud banks with the male mounted on the female's back (Winn, 1958a; 1958b; fig. 4). Strawn (1955a, 1955b) described the breeding colors of *E. lepidum* and *E. grahami* but did not mention breeding tubercles.

### Subgenus *Villora* Hubbs and Cannon

There are two species in this subgenus: *E. okaloosae* (Fowler) and *E. edwini* (Hubbs and Cannon). I have examined virtually all the available material of *edwini* and Ralph W. Yerger has done the same for *E. okaloosae* (see Collette and Yerger, 1962). Both sexes of both species are nontuberculate. Males of *E. edwini* are larger than females and have large orange-red spots over the entire body and fins. These spots are also present in females, but they are smaller and less widely distributed. Males of *E. okaloosae* are slightly larger than females and both sexes lack red spots. The genital papilla of the breeding female is a low tube crowned with villi (Collette and Yerger, 1962, fig. 7).

The larger size of males, the absence of tubercles, and the shape of the genital papilla in females are three of the characters that differentiate *Villora* from the subgenus *Hololepis*, under which it has been synonymized by Bailey (*in* Bailey and Gosline, 1955). These characters help to substantiate my belief that *Villora* is an offshoot of the *asprigene–swaini* nontuberculate group of the subgenus *Oligocephalus* (Collette and Yerger, 1962, p. 214).

### Subgenus *Austroperca* Hubbs

Males of *E. australe* Jordan, the only known species in this Mexican subgenus, taken on May 21 (UMMZ 136124, Chihuahua) and March 28 (UF 10127, Durango) have slightly enlarged testes and lack tubercles.

### Subgenus *Psychromaster* Jordan and Evermann

No tubercles are present on the available material of *E. tuscumbia* Gilbert and Swain. Three males (USNM 125096, Alabama, Tennessee R., 36–38 mm.) which were apparently taken in the spring, although the date is unknown, have greatly enlarged testes and no tubercles. A 41 mm. female in this collection is filled with moderate-sized eggs. Males in a large collection taken on May 26 (UMMZ 104244, Alabama, Wheeler Reservoir) have the testes only slightly enlarged; the females are filled with large eggs.

The second species in this subgenus, *E. trisella* Bailey and Richards, is known only from the juvenile holotype.

### Subgenus *Catonotus* Agassiz

This subgenus is composed of five described species: *flabellare* Rafinesque, *kennicotti* (Putnam), *obeyense* Kirsch, *squamiceps* Jordan, and *virgatum* (Jordan), plus several undescribed forms. All the species appear to be nontuberculate. The subgenus may, however, be divided into two species groups on the basis of another sexually dimorphic character. Both sexes of *E. kennicotti* and the males of *E. flabellare* and *E. squamiceps* have cream-colored, fleshy bulbs at the tips of the spines in the first dorsal fin. The tips of the dorsal spines in *flabellare,* and to a much lesser extent in *kennicotti,* are modified into a Y-shaped fork which supports the fleshy bulbs. These fleshy tips are essentially absent in both sexes of *E. obeyense* and *virgatum,* although small incipient bulbs are occasionally visible. Males of all species are darker than females, especially the pelvic, anal, and first dorsal fins, head, breast, and belly. Winn (1958b, p. 172) reported that males of *E. flabellare* were larger than females, had larger anal, pectoral, and pelvic fins, and lacked breeding tubercles. *E. flabellare* has a complex mating behavior which culminates in a pair spawning head to tail upside down underneath a rock (Lake, 1936, fig. 1; Winn, 1958a; 1958b, fig. 5).

### Subgenus *Hololepis* Agassiz

This subgenus consists of six species: *serriferum* (Hubbs and Cannon); *gracile* (Girard); *zoniferum* (Hubbs and Cannon); *fusiforme* (Girard), with two subspecies; *saludae* (Hubbs and Cannon); and *collis* (Hubbs and Cannon), with two subspecies (Collette, 1962). Males of all species of *Hololepis* have tubercles on the anal rays and on the undersides of the pelvic fin rays. Males are generally darker than females, especially their dorsal, anal, and pelvic fins, and the venter. Females are larger than males or of about equal size. Males of *E. gracile* and *E. zoniferum* have supplementary tubercles on the rami of the lower jaw and in life have vertical green bars on the sides and red spots on the first dorsal fin. Sexual dimorphism in these two species confirms their close relationships (Collette, 1962). Complete descriptions of coloration and breeding tubercles, photographs of sexually mature specimens, and drawings of breeding tubercles have been presented recently (Collette, 1962). Hubbs and Cannon (1935) reported tubercles in *E. serriferum*, *E. gracile*, and *E. fusiforme*.

The following account of tubercles in *Hololepis* is summarized from my recent revision (Collette, 1962). *E. serriferum* has tubercles most developed during late March, when they are present on the distal two-thirds of the anal fin rays and the distal third of the pelvic fin rays (Collette, 1962, p. 119 and fig. 1i). Hubbs and Cannon (1935) also found tubercles on the soft rays of the anal and pelvic fins of *E. serriferum*. Tubercles are present on *E. gracile* from February 19 (TNHC 4994, Texas, Red R.) to April 19 (KU 2418, Oklahoma, Red R.). Maximum development occurs in mid-March in Texas, when tubercles are present on the distal half of the anal rays, the distal three-fourths of the underside of the pelvic spine and rays, and in two rows of four tubercles on each ramus of the lower jaw (Collette, 1962 pp. 135–136 and figs. 1k, m). Hubbs and Cannon (1935) reported tubercles on the anal and pelvic fins and on the lower jaw of *E. gracile*. Cross (1954) also noted tubercles on the chin of this species. I found tubercles on only the anal rays and lower jaw rami of *E. zoniferum* (UMMZ 163758, Alabama, Tombigbee R.). I think they will be found on the pelvic rays also if sufficient material becomes available (Collette, 1962 p. 149–150). Tubercles are present on *E. saludae* from at least April 16 (CU 35019) until March 14 (CU 35036). At the maximum stage of development, tubercles are found on the distal three-fourths of the anal rays and on most of the ventral surface of the first four pelvic soft rays (op. cit., p. 191–192). In my limited material of *E. collis*, tubercles are developed on *E. c. collis* on March 22 (CU 11988) and on *E. c. lepidinion* Collette on March 31 (CU 29992). They are present on the underside of the pelvic fins and on most of the anal fin rays (op. cit., pp. 198, 205; fig. 1g).

There is geographic variation in tubercle development in *E. fusiforme*. Of thousands of specimens examined, tubercles were found on only a few specimens in 14 collections of the northern subspecies, *E. fusiforme fusiforme* (op. cit., p. 153), while they were commonly found on the southern *E. f. barratti* (op. cit., p. 175). Tubercles are present on *E. f. fusiforme* from March 25 (CU 29983, North Carolina, Ellis Lake) to May 17–18 (CU collections, New Jersey). They are present on *E. f. barratti* from October 27 (FSU 3273, Fla.) to May 29 (UG 516, South Carolina, Pee Dee R.) and are at their maximum development from March 25 to May 29. Tubercles are present on more specimens for a longer period of time and are also better developed in the southern subspecies. I have found a similar type of geographic variation in *Percina* (*Percina*) *caprodes* and *Etheostoma* (*Oligocephalus*) *spectabile*. Egami (1954) also found a north–south difference in the development of dermal contact organs on the cyprinodontid *Oryzias latipes* (Temminck and Schlegel). Hubbs and Cannon (1935) found tubercles on the anal and pelvic fins of *E. f. barratti*, but only on the anal fin of *E. f. fusiforme*.

*E. f. fusiforme* is the only form that I have watched courting. The male mounts the female and "beats" her nape with the tuberculate undersides of his pelvic fins. At the same time, his tuberculate anal fin is in contact with the posterior part of her caudal peduncle. Thus the tubercles on the pelvic fins of males of *E. f. fusiforme* may serve to stimulate the female while the anal fin tubercles aid in maintaining contact. Fletcher (1957) has presented a photograph of a spawning pair.

The presence of breeding tubercles on the pelvic and anal fins of *Hololepis* and *Microperca*, and their absence from *Villora*, is one of the reasons I feel the first two subgenera are closely related to each other and not to *Villora* (Collette, 1962).

### Subgenus *Microperca* Putnam

This most specialized subgenus of *Etheostoma*, contains three closely related species: *fonticola* (Jordan and Gilbert), *microperca* Jordan and Gilbert, and *proeliare* (Hay). Males of all three species have breeding tubercles on the anal rays and on the ventral surfaces of the pelvic fin rays as in the subgenus *Hololepis*. The fins of the males are all much darker than those of the females, especially the first dorsal, pelvic, and anal. Winn's description (1958b, p. 172) of the other sexually dimorphic features of *E. microperca* will serve equally well for the other two members of the subgenus: females larger than males; males with larger pectoral and pelvic fins; genital papillae of females elongate and tubelike; pelvic fins of males extremely long, with the outer ridge of thickened skin forming a cup (Petravicz, 1936, figs. 1, 2). The cuplike pelvic fins are furnished with tubercles which probably function in stimulation of the female or in maintenance of the spawning position (Petravicz, 1936, figs. 3, 4; Winn, 1958b, fig. 4).

Moderate sized conical tubercles are present on males of *E. fonticola* taken April 12 (USNM 166101, TU 4746, TU 5024, Texas, San Marcos R.). Tubercles are located on the distal tip of the first pelvic soft ray, on the entire length of pelvic soft rays 2–4, and on the distal half of the last pelvic soft ray. Tubercles are also present on the distal seven-eighths of all elements of the anal fin.

Two males of *E. proeliare* (USNM 165959, Mississippi, Big Black R., April 8) have tubercles on all elements of the anal fin, on the tip of the first pelvic soft ray, and on the entire length of pelvic soft rays 2–5. Seventeen males (28–32 mm. standard length) from the Red River, Louisiana (USNM 172733), taken January 12, lack tubercles as do over 40 females. Seven other males in this collection (30–32 mm.) have tubercles on the distal half of pelvic soft ray 3 and a few scattered tubercles on the distal end of the second and fourth soft rays. Two males have a few tiny tubercles on the fourth anal ray. Thus, the tubercles seem to form first on the middle soft rays of the pelvic fin, spread to the other pelvic soft rays, and then develop on the anal fin rays.

Tubercles are present on males of *E. microperca* from as early as April 16 (UMMZ 81525, Michigan, Kalamazoo R.) until as late as July 10 (UMMZ 67927, Michigan, Big Wolf Cr.). They are absent on specimens taken from July 19 to December 21 (USNM), but few specimens are available from January through March. Tubercles develop first and remain for a longer period of time on the pelvic fin rays than on the anal fin rays. The maximum development I have observed is on males taken May 3 (UMMZ 73144 and 73158, Michigan, Au Sable R.). Tubercles are present on the entire length of the ventral surfaces of all the pelvic elements and on the anal spines. I have not seen specimens with tubercles developed on any of the anal soft rays as I have in the other two species of the subgenus. This poor development of tubercles is probably correlated with the northerly occurrence of *E. microperca.* A similar situation has also been shown in *Percina* (*Percina*) *caprodes*, *Etheostoma* (*Oligocephalus*) *spectabile*, and *E.* (*Hololepis*) *fusiforme fusiforme.* Petravicz (1936) failed to find tubercles on *E. microperca*, and Winn (1958b, p. 172) reported them on only the pelvic fins. *E. microperca* spawns in an approximately vertical position on plants. The male is mounted on the female's back with his tuberculate cuplike pelvic fins clasped over her back and his tuberculate anal fin in contact with her sides (Winn, 1958b, fig. 4).

## Summary

Breeding tubercles are now known for 48 species in five genera of the Percidae. Tubercles in the Percidae are mainly distributed laterally and function primarily in facilitating contact between the male and female during the spawning act. Tubercles may have a stimulatory function, especially in the species that have them on the undersurface of the pelvic fins. Breeding tubercles are of value in classification at two levels.

First, they are present in the members of the tribe Etheostomatini, subfamily Percinae, and in the members of the tribe Romanichthyini, subfamily Luciopercinae. This fact might seem to suggest that the Romanichthyini and the Etheostomatini should be placed together, separate from the Percini and Luciopercini. When coupled with other characters, such as the reduction of the air bladder, the small body size, and the utilization of lotic rather than lentic habitats, this arrangement seems even more reasonable. However, as I have shown by using osteological characters (Collette, 1963), the relationships of the Etheostomatini are with the Percini, and those of the Romanichthyini are with the Luciopercini. Closer analysis of the distributions of tubercles confirms this. In the Etheostomatini, tubercles are concentrated on ventral and ventrolateral surfaces, such as the undersides of the pelvic fins, the anal fin, the lower part of the caudal fin, the scales on the belly, and the sides up to the lateral line. In the Romanichthyini, tubercles are concentrated on the dorsal and dorsolateral surfaces, the top of the head, the dorsal fins, the pectoral fin, and the body scales primarily above the lateral line. This difference in the distribution of tubercles may indicate a different mode of spawning in the two tribes. Unfortunately, there appears to be no information available about spawning in the members of the Romanichthyini. Breeding tubercles and other characteristics that are similar in the two tribes have probably arisen as independent adaptations to a bottom-dwelling mode of life in streams.

Within the Etheostomatini, patterns of tubercle development are useful in showing phylogenetic relationships. The character has no value at the generic level, at least if three large inclusive genera, *Percina*, *Ammocrypta*, and *Etheostoma*, are recognized. However, within each of the two larger genera (*Percina* and *Etheostoma*) tubercle patterns offer an additional character in defining subgenera and species groups within subgenera.

In *Percina*, there are five nontuberculate subgenera (*Hypohomus*, *Alvordius*, *Hadropterus*, *Swainia*, and *Cottogaster*), two tuberculate subgenera (*Percina* and *Imostoma*), and one heterogeneous subgenus (*Ericosma*). On the basis of this character, perhaps the tuberculate *P.* (*Ericosma*) *evides* is not as intimately related to the nontuberculate *P. crassa* and *P. palmaris* as previous workers have indicated.

Males of all four species in the subgenus *Ammocrypta* and the one species in the subgenus *Crystallaria*, genus *Ammocrypta*, are tuberculate. I think that the tubercle distributions in these species will be found to be virtually identical, although I have not yet seen tubercles on the anal fin of *A.* (*A.*) *pellucida* and I have found tubercles on the caudal fin of *A.* (*A.*) *clara* alone. Thus, tubercle patterns agree with other characters that lead to synonymizing *Crystallaria* with *Ammocrypta*, at least at the generic level.

The greatest problems in the classification of the Percidae lie in the largest genus, *Etheostoma*. Twelve subgenera were utilized by Bailey (*in* Bailey and Gosline, 1955) and one more recently has been recognized (Collette and Yerger, 1962).

The subgenus *Boleosoma* is composed of at least two groups: the nontuberculate *nigrum* group of five species and the tuberculate *stigmaeum* group of three species, although in some other characters, *chlorosomum* of the latter group tends to be somewhat intermediate between the two. The nontuberculate monotypic subgenus *Ioa* clearly seems to be derived from the nontuberculate *nigrum* group. Further study may lead to synonymizing *Ioa* under *Boleosoma*, and removing *E. stigmaeum*, *E. jessiae*, and *E. chlorosomum* from *Boleosoma* and placing them in *Vaillantia* Jordan. Similarities in spawning behavior between *Ioa* and the *nigrum* group in contrast to the *stigmaeum* group reinforce this idea.

The subgenus *Etheostoma* can be divided into two closely related tuberculate groups and one nontuberculate group. The *variatum* group of five species is the only one in the Etheostomatini where both sexes are tuberculate. Other authors have previously pointed out the close relations which members of the *variatum* group have to one another. The *inscriptum* group of five species differs from the *variatum* group in that only the males develop tubercles. Four of the remaining five species (*rupestre*, *histrio*, *zonale*, and *blennius*) presently placed in the subgenus form a closely related nontuberculate group. This group appears to be somewhat intermediate between the *variatum* and *inscriptum* groups on the one hand and the nontuberculate subgenus *Ulocentra* on the other. It will be necessary to await the description of some nine new species of *Ulocentra* presently in manuscript by Reeve M. Bailey before a full appraisal can be made of the relations between the *zonale* group and *Ulocentra*. The two type specimens of *E. sellare* are females caught in the spring; they are not tuberculate. Therefore, it probably should not be placed in the *variatum* group, although a number of authors have indicated that its relationships are with that group. *E. sellare* does not appear to be close to either the *inscriptum* or *zonale* groups and I am not satisfied that it belongs in the subgenus *Etheostoma*.

The monotypic subgenera *Allohistium* and *Austroperca* are apparently nontuberculate. *Psychromaster* is also apparently nontuberculate. The lack of tubercles in all species of *Nothonotus* and *Catonotus* further indicates the compact nature of each of these subgenera.

The largest subgenus, *Oligocephalus*, contains about 20 species which belong in at least four species groups. The three forms of the *nianguae* group are very closely related to each other as was noted by Bailey (1948) and Kuehne and Bailey (1961). The *radiosum* group is similar to the *nianguae* group in having tubercles on the body scales, but this may not be an indication of close relationship. The *spectabile* group consists of nine species, all of which have tubercles on the anal fins of males. All but *E. parvipinne* and *E. fricksium* of this group have tubercles on the ventral scales and the pelvic fins. *E. punctulatum*, *E. luteovinctum*, and *E. spectabile* also have additional tubercles on the lower part of the caudal fin and *E. spectabile* even has tubercles on the pectoral fin. Probably most of the remaining eight species are nontuberculate.

Both species of the subgenus *Villora* lack breeding tubercles, further indicating that *Villora* is probably an offshoot of the nontuberculate group of *Oligocephalus*, perhaps from somewhere near *E. swaini* and *E. asprigene*, and consequently it was removed from synonymy with *Hololepis* (Collette and Yerger, 1962).

The presence of breeding tubercles on the anal and pelvic fins of the species in the subgenus *Hololepis* shows its close relationships with the subgenus *Microperca* and not with *Villora* (Collette, 1962). The presence of tubercles on the chin of *E. gracile* and *E. zoniferum* confirms other evidence that these two species of *Hololepis* are especially closely related (Collette, 1962).

Thus, the patterns of breeding tubercles confirm the close relationships within many subgenera and species groups of the Percidae and indicate that several other groups may need rearranging.

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## Literature Cited

ALM, GUNNAR
1952. Year class fluctuations and span of life of perch. Ann. Rept. Inst. Freshwater Res. Drottningholm, no. 33, pp. 17–38.

ATZ, JAMES W.
1940. Reproductive behavior in the eastern johnny darter, *Boleosoma nigrum olmstedi* (Storer). Copeia, 1940, no. 2, pp. 100–106.

BAILEY, REEVE M.
1940. *Hadropterus palmaris*, a new darter from the Alabama River System. Journ. Washington Acad. Sci., vol. 30, no. 12, pp. 524–530.
1948. Status, relationships, and characters of the percid fish, *Poecilichthys sagitta* Jordan and Swain. Copeia, 1948, no. 2, pp. 77–85.
1959. *Etheostoma acuticeps*, a new darter from the Tennessee River system, with remarks on the subgenus *Nothonotus*. Occ. Pap. Mus. Zool. Univ. Michigan, no. 603, 10 pp.

BAILEY, REEVE M., and GOSLINE, WILLIAM A.
1955. Variation and systematic significance of vertebral counts in the American fishes of the family Percidae. Misc. Publ. Mus. Zool. Univ. Michigan, no. 93, 44 pp.

BAILEY, REEVE M., and RICHARDS, WILLIAM J.
1963. Status of *Poecilichthys hopkinsi* Fowler and *Etheostoma trisella*, new species, percid fishes from Alabama, Georgia and South Carolina. Occ. Pap. Mus. Zool. Univ. Michigan, no. 630, 21 pp.

BAILEY, REEVE M.; WINN, HOWARD E.; and SMITH, C. LAVETT
1954. Fishes from the Escambia River, Alabama and Florida, with ecologic and taxonomic notes. Proc. Acad. Nat. Sci. Philadelphia, vol. 106, pp. 109–164.

BECKMAN, WILLIAM C.
1949. The rate of growth and sex ratio for seven Michigan fishes. Trans. American Fish. Soc., vol. 76, pp. 63–81.

BERG, L. S.
1949. The fishes of the freshwaters of the USSR and the surrounding territory. Opredeliteli Faune SSSR, Zool. Inst. Akad. Nauk SSSR, no. 30, ed. 4, pt. 3, pp. 929–1381. [In Russian.]

CARLANDER, KENNETH D.
1950. Growth rate studies of saugers, *Stizostedion canadense canadense*

PETRAVICZ, JOSEPH J.
1936. The breeding habits of the least darter, *Microperca punctulata* Putnam. Copeia, 1936, no. 2, pp. 77–82.
PETRAVICZ, WALTER P.
1938. The breeding habits of the black-sided darter, *Hadropterus maculatus* Girard. Copeia, 1938, no. 1, pp. 40–44.
RANEY, EDWARD C.
1941. *Poecilichthys kanawhae*, a new darter from the upper New River system in North Carolina and Virginia. Occ. Pap. Mus. Zool. Univ. Michigan, no. 434, 16 pp.
RANEY, EDWARD C., and LACHNER, ERNEST A.
1939. Observations on the life history of the spotted darter, *Poecilichthys maculatus* (Kirtland). Copeia, 1939, no. 3, pp. 157–165.
1943. Age and growth of johnny darters, *Boleosoma nigrum olmstedi* (Storer) and *Boleosoma longimanum* (Jordan). American Midl. Nat., vol. 29, no. 1, pp. 229–238.
RANEY, EDWARD C., and SUTTKUS, ROYAL D.
1964. *Etheostoma moorei*, a new darter of the subgenus *Nothonotus*, from the White River System, Arkansas. Copeia, 1964, no. 1, pp. 130–139.
RAWSON, D. S.
1957. The life history and ecology of the yellow walleye, *Stizostedion vitreum*, in Lac la Ronge, Saskatchewan. Trans. American Fish. Soc., vol. 86, pp. 15–37.
REIGHARD, JACOB
1913. The breeding habits of the log-perch (*Percina caprodes*). Mich. Acad. Sci., 15th Rep., pp. 104–105.
RICHARDS, WILLIAM J., and KNAPP, LESLIE W.
1964. *Percina lenticula*, a new percid fish, with a redescription of the subgenus *Hadropterus*. Copeia, 1964, no. 4, pp. 690–701.
SMITT, F. A.
1892. A history of Scandinavian fishes, ed. 2, 1240 pp. [By B. Fries, C. V. Ekstrom, and C. Sundevall, second edition revised and completed by Smitt.]
STRAWN, KIRK
1955a. A method of breeding and raising three Texas darters, 1. Aquar. Journ., vol. 26, no. 12, pp. 408–412.
1955b. A method of breeding and raising three Texas darters, 2. Aquar. Journ., vol. 27, no. 1, pp. 12–14, 17, 31.
TRAUTMAN, MILTON B.
1957. The fishes of Ohio, 683 pp.
VLADYKOV, VADIM D.
1931. Poissons de la Russie Sous-Carpathique (Tchécoslovaquie). Mém. Soc. Zool. France, vol. 29, no. 4, pp. 217–374.
WINN, HOWARD E.
1953. Breeding habits of the percid fish *Hadropterus copelandi* in Michigan. Copeia, 1953, no. 1, pp. 26–30.
1958a. Observations on the reproductive habits of darters (Pisces-Percidae). American Midl. Nat., vol. 59, no. 1, pp. 190–212.
1958b. Comparative reproductive behavior and ecology of fourteen species of darters (Pisces–Percidae). Ecol. Monog., vol. 28, pp. 155–191.
WINN, HOWARD E., and PICCIOLO, ANTHONY R.
1960. Communal spawning of the glassy darter *Etheostoma vitreum* (Cope). Copeia, 1960, no. 3, pp. 186–192.

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# Recent Studies on the Needlefishes (Belonidae): An Evaluation

Bruce B. Collette and Frederick H. Berry

RECENT STUDIES ON THE NEEDLEFISHES (BELONIDAE): AN EVALUATION. Data on Six Species of Needlefishes (Belonidae) from the Western Atlantic, by F. H. Berry and L. R. Rivas, Copeia 1962 (1):152–160. A Preliminary Revision of the Belonidae, by G. F. Mees, Zoologische Verhandelingen 1962, No. 54, 96 p. Further Revisional Notes on the Belonidae, by G. F. Mees, 1964, Zoologische Mededelingen 39: 311–326.

Comparison of these 3 recent papers on needlefishes reveals that their authors disagree on the names for all species of Belonidae found along the coasts of the American continents. Preparation of the account on Belonidae for *Fishes of the Western North Atlantic* has made it necessary to attempt to resolve the conflicts in these papers. The paper by Berry and Rivas is a review of the family in the western Atlantic Ocean, based on a large amount of material from that area. Mees has attempted to review the family on a worldwide basis but with limited material, although his review of pertinent early literature is thorough. Both approaches have their strengths and weaknesses. Some of the nomenclature used by Berry and Rivas is incorrect, because they did not compare western Atlantic forms with related forms in other parts of the world. Mees' analysis, on the other hand, is frequently superficial, because he did not examine adequate material of some species and did not examine type-specimens in several major collections. His generic concepts are at odds with those of most other recent workers on synentognath fishes.

Conflicts over names of western Atlantic and eastern Pacific needlefishes are primarily due to the authors' different opinions or philosophies in 3 general areas: 1. *Genera*: Berry and Rivas used 4 genera for the Belonidae in the western Atlantic Ocean, whereas Mees recognized 3 genera in the entire world in his 1962 review and 2 in his 1964 paper. (About 10 genera have been widely used in the family.) 2. *Distribution*: Mees found that many of the species of needlefishes have larger ranges than earlier workers believed. Examples given by Mees of worldwide species with different names in different major regions were: *crocodila–raphidoma–fodiator*, *acus–melanota–pacifica*, and *argalus–platyura–persimilis*. 3. *Acceptance of early works*: Mees introduced different names for several species of Belonidae that had generally accepted names. In doing so, he ignored the provisions of Article 23b of the International Code of Zoological Nomenclature limiting absolute priority. Often he rejected a given name as unidentifiable but adopted another name based on an equally poor description.

Although we have not completed sufficient research to enable us to provide definitive answers to all problems in belonid classification, we should like to offer a classification that will resolve the conflicts in the aforementioned papers.

### *Genera*

Early workers included a wide variety of species in their genera. The 9 species that Linnaeus originally included in his genus *Esox* now are placed in as many families. With time, so many genera were described in some groups that many of them became monotypic, and nomenclature became virtually uninomial. Twenty genera were erected for the approximately 25 valid species of Belonidae. Mees (1962, 1964) has gone to the other extreme by placing 18 genera in the synonymy of *Belone*. Mees was aware that many genera were originally poorly diagnosed, but he was influenced in his nomenclatural decisions by these diagnoses, and did not investigate other characters. Early workers used a large amount of intuition in the art of taxonomy and frequently put down only one or a few characters as key characters to differentiate their taxa. Mees was apparently overly impressed by characters used in keys and rejected what he called "one-character-genera," although in fact many of these rejected genera have numerous additional characters that distinguish them from other genera. He also was opposed to monotypic genera in principle, but we feel strongly that the small size of a taxon, *per se*, is not sufficient reason for placing it in synonymy.

Mees' tendency to lump taxa merely because they are small was not confined to the generic level in the Belonidae as may be seen from his discussion (1962:3) of the classification of the family: "The Belonidae form a well-defined natural group consisting (as my investigations show) of not over about 30 species. Because of its smallness one is inclined to wonder if this group really deserves family status. Though for the moment I follow an authority as Berg (1940, 1955) in considering them a family, the fact that the Hemiramphidae have many characters in common with the Belonidae (even the green bones) shows that it may be justified to reduce these two groups to sub-family status." The Belonidae is a well-defined family and its closest affinity within the order Synentognathi is not with the Hemiramphidae, but with the Scomberesocidae as shown by Regan (1911, Ann. Mag. Nat. Hist. 7:327–335), Nichols and Breder (1928, Zoologica 8 (7): 423–448), and others. The Hemiramphidae are related to the Exocoetidae. Mees did not mention the Exocoetidae or the Scomberesocidae. In the suborder Scomberesocoidea, the upper pharyngeal bones are separate, whereas in the Exocoetoidea the left and right third pharyngeal bones are joined in a manner analogous to the fusion of the lower pharyngeals throughout the Synentognathi.

We recognize the following 9 genera of Belonidae:

*Belone* Cuvier, 1817 (type-species by monotypy, *Esox belone* Linnaeus, 1758). We restrict the genus *Belone* to the species *belone*, because characters such as the presence of gill rakers, strongly compressed body, shape of the preorbital canal, strongly forked caudal fin, peculiar arch of the anterior portion of the upper jaw, and occasional presence of vomerine teeth indicate that *Belone belone* is close to the basic stock of Belonidae and is not on one of the other phyletic lines within the family. In several characters, such as possession of gill rakers and moderate numbers of vertebrae and dorsal, anal, and pectoral rays, *Petalichthys* is close to *Belone* (*sensu stricto*) and may ultimately have to be synonymized with it.

*Petalichthys* Regan, 1904 (type-species by monotypy, *Petalichthys capensis* Regan, 1904). Mees (1962:52) justified putting *Petalichthys* into the synonymy of *Belone* primarily on the grounds that Regan first compared it with *Scomberesox* instead of *Belone*. Mees indicated that the few large scales present in *Petalichthys* (about 70) is not a valid generic character because of the wide variation in number of scales (120–400) in the other species of the family. Mees failed to consider the continuum of variation in this character among the other species; only *capensis* is distinctly different. In our opinion, this type of separation can be valid basis for generic status.

*Platybelone* Fowler, 1919 (type-species by original designation, *Belone platyura* Bennett, 1832). In placing this genus in the synonymy of *Belone*, Mees did not consider whether the strongly depressed caudal peduncle, totally unlike that of any other needlefish, could be used as a generic character. He negated the value of the presence or absence of gill rakers in the classification of the Belonidae because they are present in *Belone*, *Petalichthys*, and *Platybelone*. These 3 genera with gill rakers may be members of different evolutionary lines, each meriting recognition. We believe *Platybelone* should be used for the *argalus–platyura–persimilis* population because such characters as the depressed caudal peduncle, shape of the preorbital canal, presence of gill rakers, and large difference in length between the upper and lower jaws (see Berry and Rivas, Fig. 1a, and page 158) indicate that this is a distinct line of evolution within the family.

*Strongylura* van Hasselt, 1824 (type-species by monotypy, *Strongylura caudimaculata* van Hasselt, 1824 [= *Belone strongylura* van Hasselt, 1823]). This is the only genus that Mees (1962:13) attempted to discuss adequately before placing it in the synonymy of *Belone*. Mees discounted the value of gill rakers as a character separating *Belone* from *Strongylura* by including *Platybelone argalus* in the discussion. The presence of a keel on the caudal peduncle of *Tylosurus*, a character that differentiates it from *Strongylura*, was rejected by Mees (1964:13) as ". . . a character that nowadays (for reasons unknown to me) is not considered to be of generic value. . . ." *Strongylura* differs from *Tylosurus* in having small pelvic fins, a rounded or truncate caudal fin, a moderate number of vertebrae, and most importantly, in lacking a melanistic lobe in the dorsal fin of juveniles.

*Tylosurus* Cocco, 1833 (type-species by monotypy, *Tylosurus cantrainii* Cocco, 1833). Berry and Rivas recognized *Tylosurus* as generically distinct from *Strongylura* in the western Atlantic Ocean. The difference in number of dorsal fin rays used as a key character by Berry and Rivas is not of fundamental importance in distinguishing between these genera. However, it is one of the characters that can be used to separate most species of *Strongylura* from most species of *Tylosurus*. The most important generic character is the presence in juvenile *Tylosurus* (and *Ablennes*) of a melanistic lobe in the dorsal fin, which sloughs off during development (see Breder and Rasquin, 1952, Bull. Am. Mus. Nat. Hist. 99:1–23). Such features of development are extremely important in the classification of synentognath fishes and must be well studied before a definitive classification of the order will be possible. An interesting parallel exists between certain Hemiramphidae and Belonidae from offshore and inshore habitats. Offshore Hemiramphidae (*Hemiramphus*) and Belonidae (*Tylosurus* and *Ablennes*) have similar characters such as the melanistic fin lobes in juveniles, a forked caudal fin with the lower lobe much better developed than the upper, and large forked pelvic fins. The more inshore-dwelling Hemiramphidae (*Hyporhamphus*) and Belonidae (*Strongylura*) lack these characters and have differentiated into distinct species in different oceans and on opposite sides of the same ocean.

One of the disadvantages of the all-inclusive genus *Belone* is that relationships within the genus are obscured. In Mees' key (1962: 9) all the nominal forms that we refer to *Tylosurus* (*fodiator, punctulata, marisrubri, melanota*, and *imperialis*), except *gavialoides*, are in one group of couplets, and yet he (1964:313) admitted to failure in the synthesis of relationships. In other words, parts of Mees' key express relationships better than his text does.

*Ablennes* Jordan and Fordice, 1887 (type-species by original designation *Belone hians* Valenciennes, 1846). Mees (1962:29) stated that the characters separating *Ablennes* from the other species of Belonidae were "only the slender build and the elevation of the premaxillaries near the base." He then rejected the genus because some other species also have slightly elevated maxillaries; the slender "build" is not a generic character; and one author had included (mistakenly) a species of *Strongylura* in *Ablennes*. We feel that the greatly compressed body of *Ablennes* is an important differentiating character, and that retention of the genus is justified when this feature is coupled with other characters such as the prominent crossbands on the body, large number of vertebrae, elongate lower pharyngeal plate, melanistic posterior dorsal lobe, porous preorbital bone, and offshore habitat. In some characters, *Ablennes* is analogous to the ecologically similar genus *Euleptorhamphus* in the Hemiramphidae.

*Xenentodon* Regan, 1911 (type-species *Esox cancila* Hamilton-Buchanan, 1882). Regan created this genus because of a difference in pharyngeal dentition. Mees (1962:21) wrote, "As I have not anatomically studied any member of the Belonidae, I am not able to judge the systematic value of this character, but now that the number of species of *Xenentodon* has been reduced to one, there is, at least from a practical point of view, nothing to be gained by admitting the genus. . . ." We fail to see how a genus can be put into synonymy by ignoring the diagnostic character on which it was based. Not only does *Xenentodon* differ from all described genera of synentognaths in having only the third pair of upper pharyngeals dentigerous, but it differs also in having a lower pharyngeal plate that is long, narrow, and pointed at both ends. Other species of synentognaths have a basically triangular lower pharyngeal plate.

*Pseudotylosurus* Fernández-Yépez, 1948 (type-species by monotypy *Pseudotylosurus brasiliensis* Fernández-Yépez, 1948). Mees recognized this genus in 1962 because of its spine-bearing scales, but in 1964 he placed *P. brasiliensis* in *Belone* because he felt that *Pseudotylosurus* was based on only a single character. In our opinion, a character that is unique within an order is certainly sufficient to define a genus. There are, in addition, other distinguishing characters—the peculiar side branches of the lateral line, the relatively elongate lower pharyngeal plate, the simplified preorbital canal, and the depressed caudal peduncle. Mees' willingness to reject *Pseudotylosurus* lies, in part, in his not recognizing that *Belone angusticeps* Günther (which Mees placed in *Strongylura*) is a senior synonym of *P. brasiliensis*. He apparently overlooked the spine-bearing scales on the type specimen that he examined in the British Museum.

*Potamorrhaphis* Günther, 1866. As Mees (1964:314) noted, Günther included 2 species in his new subgeneric unit—*B. taeniata* Günther, 1866, and *B. scolopacina* Valenciennes, 1846. Günther's account of the latter was based only on Valenciennes' description. Therefore, it is obvious that the characters of *Potamorrhaphis* were based on Günther's own material, so we feel the nominal species *Belone taeniata* Günther should be the type-species of *Potamorrhaphis*. We agree completely with Mees that *Potamorrhaphis* is a distinct genus, and we can add to his diagnostic characters. *Potamorrhaphis* has fewer (7 or 8) pectoral rays than any other needlefish yet described. It is the only described genus of synentognaths that has fewer than 7 + 8 principal caudal rays—Mees noted that the caudal fin was "somewhat degenerated."

### *Distribution*

The most valuable contribution in Mees' 1962 paper came from his attempt to study the family on a worldwide basis. Workers on other groups of epipelagic marine fishes (tunas of the genus *Thunnus*: Gibbs and Collette, MS; sharks of the genus *Carcharhinus*, Garrick, MS; and large species of jacks, *Caranx*, *Uraspis*, etc., Berry, MS) are discovering that many species have wider distributions than were previously suspected. Several of the names used by Berry and Rivas need to be changed, because they were dealing with a form that had been described earlier from another region.

*Ablennes* and *Platybelone* both have wide distributions but show relatively little geographic variation in most characters. Eastern Pacific populations of both of these monotypic genera (and of 2 species of *Tylosurus*) have a reduced number of vertebrae.

Within the genus *Tylosurus* (*sensu* Collette and Berry), 2 species groups have worldwide distributions. Mees (1962) recognized 1 group, which he called *Belone maris-rubri* (Bloch and Schneider), as having an eastern Pacific subspecies, *B. m. fodiator* (Jordan and Gilbert). *B. m. marisrubri* is the same as Berry and Rivas' *T. raphidoma* (Ranzani) in the western Atlantic Ocean, and what we now have decided (see below) should be called *T. crocodilus* (Peron and LeSueur). In his 1962 publication, Mees did not recognize the existence of the other group. He attempted to correct this oversight in his 1964 paper by making *melanota* and *pacifica* subspecies of *imperialis*. We can find no grounds for separating the Indo-Pacific *melanota* from the Atlantic population which Berry and Rivas called *T. acus* (Lacépède). The eastern Pacific populations of both species have reduced numbers of dorsal and anal rays and vertebrae, and so may merit subspecific recognition.

The eastern Pacific geminate species of the western Atlantic *S. marina* (Walbaum) (= *Belone houttuyni* of Mees) is *Strongylura exilis* (Girard). We find no reason to recognize *Belone stolzmanni* Steindachner as a subspecies of *S. exilis* as Mees did. The development of a spot in the pectoral fin varies widely, although it is more likely to be developed on specimens from the southern part of the range than on those from the northern part.

The second western Atlantic species of *Strongylura* is *S. notata* (Poey). We support Mees' placement of *Strongylura notata forsythia* Breder in synonymy after our examination of the type of this subspecies and extensive additional material. We agree with Mees' suggestion (1962:69) of the similarity of *S. notata* to *S. urvillii* (Valenciennes) and add that they both have few vertebrae (55–60 in *notata*, 58–59 in *urvillii*).

### *Acceptance of early works*

With the system of binominal nomenclature, changes in names necessarily will accompany increases in knowledge. Biologists and others who are not systematists must also use these names, so each systematist is obligated not to make unnecessary changes. A generally accepted name of dubious validity should not be replaced by another name of equally dubious validity that has had little or no usage. One undesirable aspect of Mees' 1962 paper is his predilection for changing names unnecessarily. In several instances his action is in direct contradiction to the provisions of the 50-year rule (Article 23b, Int. Code Zool. Nomencl.).

Mees (1962:34–36) rejected the time-honored *Strongylura marina* (Walbaum, 1792) in favor of *houttuyni* described by Walbaum on the same page of the same paper and not used since. Mees considered both names applicable and changed the name of the commonest species of needlefish in the western Atlantic Ocean, because he preferred the name that honored his countryman Houttuyn. He followed this chauvinistic reasoning with an even more remarkable statement: "Many names in the genus *Belone* have so often been misused that it is perhaps an advantage to have a set of nomenclatorially clean names available to replace them." Certainly, the provisions of the 50-year rule should have been followed here. We have applied (Collette and Berry, in press, Bull. Zool. Nomencl.) to the International Commission on Zoological Nomenclature to suppress *Esox houttuyni* Walbaum as a *nomen oblitum*.

Mees (1962:71) considered the name *Belona argalus* LeSueur, 1821 as unidentifiable because of the high number of fin rays he counted in the figure which accompanied the original description and because LeSueur ". . . does not clearly mention the very broad caudal carina." The figure clearly shows the depressed caudal peduncle diagnostic of *Platybelone*, the number of fin rays given in the text is correct (the fin rays in the figure appear to be diagrammatic), and we will continue to use the specific name *argalus* for this group as Berry and Rivas have done for the western Atlantic population. From the data given by Mees and our examination of many additional specimens, it seems probable that *Platybelone argalus* is a single worldwide species, although there is geographical variation in number of vertebrae that still needs to be explained.

One of the best-documented cases of worldwide distribution that Mees presented concerns the species that he called *Belone marisrubri* (Bloch and Schneider, 1801), based on a Red Sea specimen. In accordance with western Atlantic precedent, Berry and Rivas used the name *Tylosurus raphidoma* (Ranzani, 1842) which was based on a Brazilian specimen. Ranzani's name has several senior synonyms and so should not be used. However, we can not agree with Mees on the use of *marisrubri.* Instead of following Weber and de Beaufort (1922, Fishes Indo-Australian Arch. 4) and most other modern authors in using *Belona crocodila* Peron and LeSueur, 1821 (type-locality Mauritius), for this species, Mees used *Esox belone* var. *Maris rubri* (Bloch and Schneider, 1801) which was based on Forskål (1775, Descriptiones Animalium). Mees pointed out that *marisrubri* was validly introduced according to our present rules, though for only a variety, but added that the name ". . . apparently has not been used since its introduction. . . ." The name *marisrubri* clearly is a *nomen oblitum* and we have requested (Collette and Berry, in press, Bull. Zool. Nomencl.) the International Commission to suppress it in favor of *Belona crocodila.*

The other circumtropical species or species group of *Tylosurus* has 3 early names that might apply—*Sphyraena acus* Lacépède, 1803, *Esox imperialis* Rafinesque, 1810, and *Belona carribaea* LeSueur, 1821—but none of these nominal species was adequately described, and each might be considered to relate to *T. crocodilus.* Berry and Rivas (1962) used *T. acus* for this species, because this name has been associated with the more slender-snouted *Tylosurus* in the western Atlantic Ocean since Jordan and Fordice (1887, Proc. U. S. Nat. Mus. 9:356). Mees rejected *acus* as unidentifiable, but he did not know that the species in question can have as many dorsal and anal fin rays as was described for *acus* (D. 25, A. 24). Mees accepted *imperialis,* type-locality Sicily, for this species, because he believed that only one species of *Tylosurus* occurred in the Mediterranean; we now know that both circumtropical species of *Tylosurus* occur there. Until Mees (1962), the name *imperialis* had not been used as a senior synonym for this species for well over 50 years. Therefore, we have applied to the International Commission to reject it as a *nomen oblitum* (Collette and Berry, in press, Bull. Zool. Nomencl.). We accept *acus* as the proper name for this species, because it is the oldest available name that can apply to this species and because it is the name most frequently associated with it for many years.

In conclusion, we presently believe that 9 genera should be maintained for the approximately 26 valid species in the Belonidae. The 7 genera listed first are apparently monotypic. *Belone* and *Petalichthys* appear closely related and are restricted to the eastern Atlantic Ocean. *Potamorrhaphis* and *Pseudotylosurus* are confined to South American fresh waters, and *Xenentodon* to Asian fresh waters. *Ablennes* and *Platybelone* are wide ranging, primarily offshore genera. *Tylosurus* contains about 5 species, 2 of which are wide ranging. *Strongylura* contains about 12 species with comparatively restricted ranges. The 3 freshwater genera appear to have been independently derived from *Strongylura. Ablennes* is a specialized offshoot of *Tylosurus. Belone* appears to represent the most primitive stock of the family, and *Strongylura, Tylosurus,* and *Platybelone* appear to have been independently derived from it.

Pending completion of further research, we recommend that the following names be used for the species of needlefishes that occur in the western Atlantic and eastern Pacific oceans. Below the recommended names are listed the names used by Berry and Rivas (1962) and Mees (1962, 1964).

### Western Atlantic Ocean

*Ablennes hians* (Valenciennes, 1846)
= *A. hians*—Berry and Rivas
= *Belone hians*—Mees

*Platybelone argalus* (LeSueur, 1821)
= *Belone argala*—Berry and Rivas
= *B. platyura* Bennett, 1832—Mees

*Tylosurus acus* (Lacépède, 1803)
= *T. acus*—Berry and Rivas
= *Belone imperialis* (Rafinesque, 1810)—Mees 1962
= *B. i. imperialis*—Mees 1964

*Tylosurus crocodilus* (Peron and LeSueur, 1821
= *T. raphidoma* (Ranzani, 1842)—Berry and Rivas
= *Belone maris-rubri maris-rubri* (Bloch and Schneider, 1801)—Mees

*Strongylura marina* (Walbaum, 1792)
= *S. marina*—Berry and Rivas
= *Belone houttuyni* (Walbaum, 1792)—Mees

*Strongylura notata* (Poey, 1860)
= *S. notata*—Berry and Rivas
= *Belone notata*—Mees

Eastern Pacific Ocean

*Ablennes hians*

*Platybelone argalus*

*Tylosurus acus* or *T. acus pacificus* (Steindachner, 1876)
= *Belone imperialis pacifica*—Mees 1964

*Tylosurus crocodilus* or *T. crocodilus fodiator* Jordan and Gilbert, 1882
= *Belone marisrubri fodiator*—Mees 1964

*Strongylura exilis* (Girard, 1854)
= *Belone exilis exilis* and *B. e. stolzmanni* Steindachner, 1873—Mees

*Strongylura scapularis* (Jordan and Gilbert, 1882)
= *Belone scapularis*—Mees 1964

*Strongylura fluviatilis* (Regan, 1903)
= *Belone fluviatilis*—Mees

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# The Distribution and Behaviour of Pelagic and Early Demersal Stages of Haddock in Relation to Sampling Techniques.

BY JOHN B. COLTON, JR.

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## B-5

# THE DISTRIBUTION AND BEHAVIOUR OF PELAGIC AND EARLY DEMERSAL STAGES OF HADDOCK IN RELATION TO SAMPLING TECHNIQUES

By

John B. Colton, Jr.[1]

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## ABSTRACT

Data is presented on the vertical distribution and diurnal variation in the catch of haddock eggs, larvae, and pelagic juveniles, and on the diurnal variation in the catch of the early demersal stages of haddock in the Gulf of Maine.

Haddock eggs were concentrated in the surface layers and there was a decrease in their abundance with an increase in depth. Haddock larvae and pelagic juveniles were concentrated within a limited depth stratum, the depth limits of which were defined by the thermocline. There were no significant diurnal differences in the catch or in depth distribution of larval and juvenile haddock during surveys in which high-speed samplers having a high ratio of effective filtering area to sampling aperture were used.

The otter trawl catch of young-of-the-year and one-year-old haddock was greater during the night while the catch of 2+ year haddock was greater during the day. The diurnal variation in the catch of 2+ year haddock is due to a change in availability resulting from a movement off the bottom during th night, while the diurnal variation in the catch of young-of-the-year and one-year-old haddock appears to be due to an increase in avoidance or escape through the trawl meshes during the day.

Suggestions are made regarding sampling techniques which take cognizance of these distribution and behaviour patterns.

## INTRODUCTION

Fishery biologists have been spared for the most part the heavy pressure for predictions that has long beset the meteorologist. A most important goal and primary obligation of fishery biologists, however, is to prepare predictions of value to the industry regarding the relative abundance of fish, the years when fish will be abundant and the areas where fish will concentrate. But what is more significant, the proof of our understanding of what is happening in the sea is the ability to specify what will happen next. In order to assess the seasonal and yearly fluctuations in distribution and abundance of fish and to make predictions regarding future availability and size of stock, it is essential that we conduct census surveys of these populations before they enter the commercial fishery. Although sampling is the heart of such studies, a more thorough examination of sampling techniques and of distribution and behaviour patterns is needed before reliable estimates and predictions of abundance and distribution can be made.

The problems involved are complex, for populations of fish are not static and are not distributed randomly in either time or space. The vertical and horizontal distribution of fishes varies with the stage of development, season of the year and time of day. In addition, many species of fish are able to avoid or escape from standard collecting gear, and this ability also varies with the stage of development and time of day. It is the purpose of this paper to present data on the vertical distribution of haddock eggs, on the vertical distribution and diurnal variation in the catch of larvae, pelagic juveniles and early demersal stages of haddock in the Gulf of Maine - Georges Bank area. Sampling techniques are suggested which take cognizance of these distribution and behaviour patterns and which are possibly applicable to other species of fish.

## VERTICAL DISTRIBUTION OF HADDOCK EGGS

There have been three surveys in the Gulf of Maine - Georges Bank area in which quantitative samples were obtained in a suitable form for analysis of the vertical distribution of haddock eggs. The first series of observations was made during March, April, May and June, 1931 and April, 1932, in connection with a study of the distribution and survival of haddock eggs and larvae on Georges Bank (Walford, 1950). Sampling consisted of 30-min oblique tows with 1-m nets at a towing speed of 1.5 knots. In depths less than 100 m two nets were used, and in depths of 100 m or more three nets were used. The approximate depth ranges of the three strata sampled were 0 m to 55 m, 55 m to 110 m and 115 m to 170 m.

In Table 1 the average abundance and percentage of haddock eggs by depth strata are tabulated for stations where two nets were used in series (78 stations) and for stations where three nets were used in series (36 stations). These values were determined from Walford's Tables 4 and 5, p. 64-65. His values of eggs per minute have been converted to eggs per cubic metre.

TABLE 1.—THE AVERAGE ABUNDANCE AND PERCENTAGE OF HADDOCK EGGS BY DEPTH STRATA, MARCH - JUNE, 1931 AND APRIL 1932

| | Depth strata | No. of eggs per cubic metre | Percent |
|---|---|---|---|
| 2 strata | 0 m - 55 m | 0.258 | 70 |
| stations | 55 m - 110 m | 0.111 | 30 |
| 3 strata | 0 m - 55 m | 0.034 | 87 |
| stations | 55 m - 110 m | 0.002 | 5 |
| | 115 m - 170 m | 0.003 | 8 |

Although there was considerable variation in the relative abundance of eggs in the three depth strata between individual stations, in only 5 of the 78 stations where tows were made at two levels were more eggs taken in the second stratum than in the upper stratum. In only 2 of the 36 stations where tows were made at three levels were more eggs taken in the deepest stratum than in the upper two strata. Eggs were found throughout the water column at most stations, but by far the majority of eggs were in the upper 55 m of the water column and in shallower water areas.

The second series of data was collected on Georges Bank in the springs of 1940 and 1941 in connection with studies of the distribution of *Sagitta elegans* (Clarke, *et al.*, 1943). The tabulations of fish eggs and larvae collected during these cruises have been placed at our disposal by Dr Clarke. Briefly, the zooplankton was collected by means of quantitative oblique hauls with Clarke-Bumpus Samplers (Clarke and Bumpus, 1950) arranged vertically to divide the total depth of water into two or three strata. The samplers were equipped with No. 2 silk nets and hauls were made at a speed of approximately 2 knots. The depth strata to be sampled were designated as follows:

| Stratum | Water depth less than 75 m | Water depth more than 75 m |
|---|---|---|
| Shallow | 0 m to 25 m | 0 m to 25 m |
| Second Depth | 25 m to bottom | 25 m to half distance to bottom (or half distance to 200 m) |
| Deep | - - - - - - - | Remaining distance to bottom (or to 200 m). |

The average depths actually sampled were as follows: "Shallow",- 0 m to 22 m, "Second Depth", - 22 m to 56 m, and "Deep", - 66 m to 104 m.

For each station the number of eggs per cubic metre was calculated for each stratum, and the total number of eggs under each square metre of sea surface was determined by multiplying the number per cubic metre for each stratum by its thickness and then adding the products. The average number of eggs per cubic metre for the whole water column at each station was obtained by dividing the number of eggs under each square metre by the total depth of water sampled at each station.

The abundance of haddock eggs in each depth stratum is presented in Table 2. The data are shown for individual cruises and also include the seasonal average and percentage at each depth.

TABLE 2.—THE ABUNDANCE (NUMBER PER CUBIC METRE) AND PERCENTAGE OF HADDOCK EGGS BY DEPTH STRATA AT TWO AND THREE LEVEL STATIONS, THROUGH - JUNE, 1940 AND 1941

| | 1940 | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | *Atlantis* Cruise No: | 95 | 96 | 97 | 98 | 100 | Avg | Percent |
| | Date: | 21 March 2 April | 17-27 April | 9-16 May | 1-8 June | 19-27 June | | |
| 2 level stations | shallow 0 m - 22 m | 1.12 | 1.98 | 2.04 | 0.12 | 0.01 | 1.05 | 57 |
| | second depth 22 m - 56 m | 1.03 | 1.46 | 1.42 | 0.08 | 0 | 0.80 | 43 |
| 3 level stations | shallow 0 m - 22 m | 1.92 | 2.47 | 2.46 | 0.11 | 0.01 | 1.39 | 47 |
| | second depth 22 m - 56 m | 1.42 | 2.16 | 1.19 | 0.07 | 0 | 0.96 | 33 |
| | deep 66 m - 104 m | 0.45 | 1.69 | 0.74 | 0.03 | 0 | 0.58 | 20 |

| | 1941 | | | | | | |
|---|---|---|---|---|---|---|---|
| | *Atlantis* Cruise No: | 112 | 113 | 114 | 116 | Avg | Percent |
| | Date: | 21 March 2 April | 15-23 April | 7-14 May | 28 May 4 June | | |
| 2 level stations | shallow 0 m - 22 m | 3.00 | 2.90 | 1.91 | 0.26 | 2.02 | 61 |
| | second depth 22 m - 56 m | 0.96 | 1.66 | 2.41 | 0.16 | 1.30 | 39 |
| 3 level stations | shallow 0 m - 22 m | 4.11 | 2.53 | 1.54 | 0.25 | 2.11 | 58 |
| | second depth 22 m - 56 m | 1.00 | 0.88 | 1.99 | 0.13 | 1.00 | 27 |
| | deep 66 m - 104 m | 0.77 | 0.64 | 0.75 | 0.06 | 0.56 | 15 |

In both 1940 and 1941 the average abundance of haddock eggs decreased with depth. The relative abundance in the three depth strata varied considerably between cruises, but with the exception of Cruise 114 in May 1941, when eggs were slightly more abundant in the second depth stratum in both two and three level stations, eggs were more abundant in the upper stratum during all months. The average depth range of the upper two strata (0 m to 56 m) sampled during the 1940-41 cruises coincides with the depth range of the upper stratum sampled during the 1931-32 cruises (0 m to 55 m) and confirms the finding that haddock eggs are more abundant in the upper 50 m of the water column. In addition, it is seen that haddock eggs are most abundant in the upper 20 m of the water column.

The third series of data was collected during the Continuous Plankton Recorder surveys of the Gulf of Maine - Georges Bank area during March, April and May, 1953 and February, March, April and May 1955 and 1956. These surveys were designed to locate spawning areas and to study the effects of associated environmental factors upon the survival of haddock eggs and larvae. During these cruises Recorders were towed at a speed of 10 knots, one just below the surface and one at 10 m. The average abundance (catch per cubic metre) and percentage of early stage eggs (from fertilization to the approach of the germinal ring to the equatorial position), late stage eggs (from the equatorial position of the germinal ring to hatching), and total eggs at the surface and 10 m during 1953, 1955 and 1956 are presented in Table 3.

TABLE 3.—THE ABUNDANCE AND PERCENTAGE OF HADDOCK EGGS AT THE SURFACE AND 10 m DURING 1953, 1955 AND 1956

| | | Early stage eggs | | Late stage eggs | | Total eggs | |
|---|---|---|---|---|---|---|---|
| | | No. / $m^3$ | % | No. / $m^3$ | % | No. / $m^3$ | % |
| 1953 | Surface | 0.024 | 89 | 0.079 | 88 | 0.103 | 88 |
| | 10 m | 0.003 | 11 | 0.011 | 12 | 0.014 | 12 |
| 1955 | Surface | 0.088 | 77 | 0.053 | 79 | 0.141 | 78 |
| | 10 m | 0.026 | 23 | 0.014 | 21 | 0.039 | 22 |
| 1956 | Surface | 0.097 | 56 | 0.102 | 61 | 0.198 | 58 |
| | 10 m | 0.076 | 44 | 0.065 | 39 | 0.141 | 42 |

Although the proportion of eggs at the surface and at 10 m varied between years and between cruises within a given year, the proportion of early stage and late stage eggs at the surface and at 10 m was similar within each year, during all years both early and late stage eggs were most abundant at the surface. There were only two cruises in which haddock eggs were taken in greater numbers at 10 m than at the surface. In February 1963, 68% of the late stage eggs and in March 1963, 63% of the early stage eggs were found at 10 m.

The corroborative evidence from the three series of surveys demonstrates that although haddock eggs are present throughout the whole water column, eggs in all stages of development are concentrated in the surface layers, and there is a decrease in abundance with an increase in depth. To my knowledge there have been no detailed studies made of the vertical distribution of haddock or other gadoid eggs in other areas, but the observations of Sette (1950), Silliman (1943) and Kramer (1960) which showed that the eggs of the Atlantic mackerel (*Scomber scombrus*), Pacific sardine (*Sardinops caerulea*) and Pacific mackerel (*Pneumatophorous diego*) were concentrated in the upper 20 m of the water column and above the thermocline, and of Farris (1961) who found jack mackerel (*Trachurus symmetricus*) confined to the upper 40 m of the water column, indicate that vertical segregation occurs in the eggs of many species and in many areas.

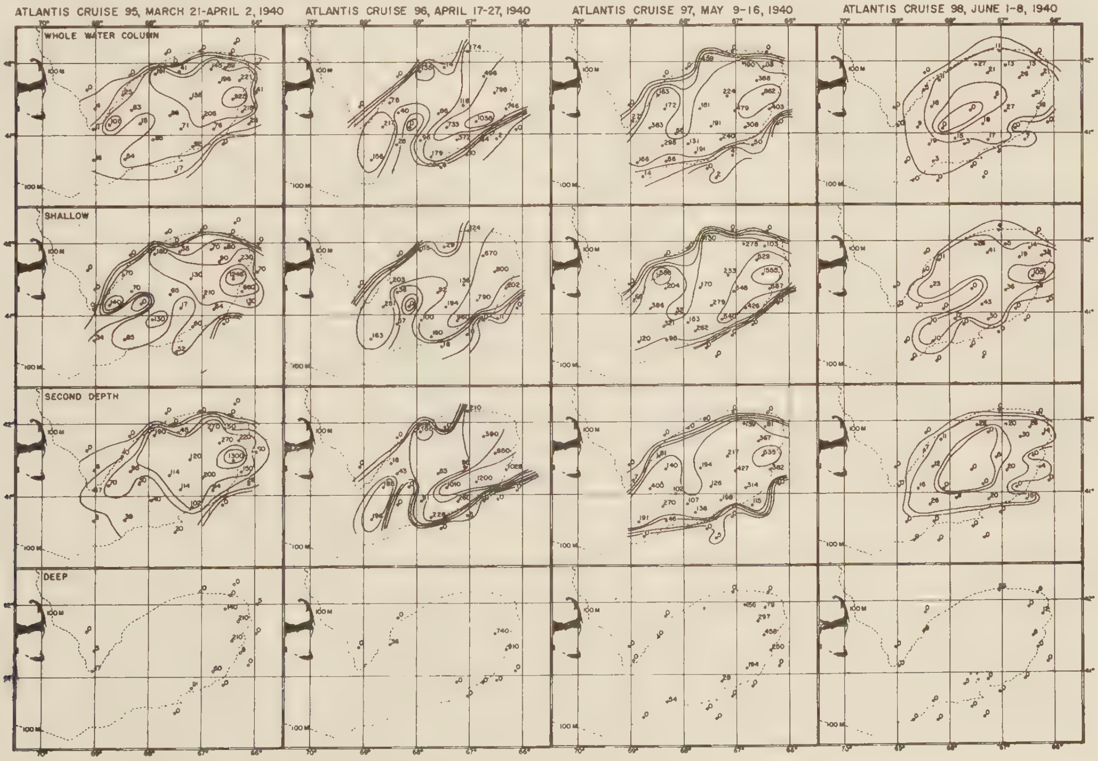

ATLANTIS CRUISE 95, MARCH 21-APRIL 2, 1940
ATLANTIS CRUISE 96, APRIL 17-27, 1940
ATLANTIS CRUISE 97, MAY 9-16, 1940
ATLANTIS CRUISE 98, JUNE 1-8, 1940
WHOLE WATER COLUMN
SHALLOW
SECOND DEPTH
DEEP
100 M

Fig. 1. Distribution of haddock eggs by depth strata, March-June 1960. Values are the number of eggs per 100 cubic metres.

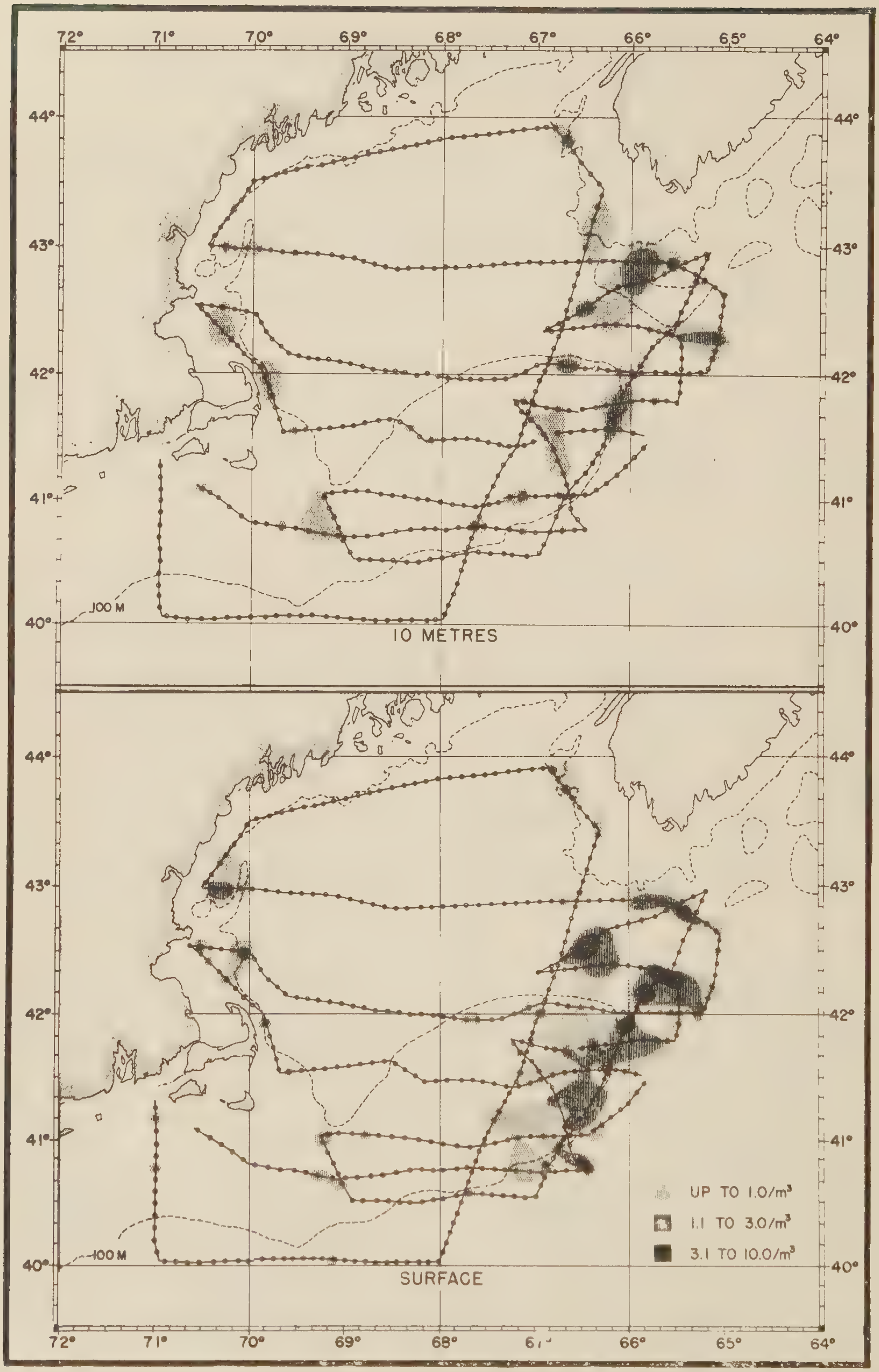

72°
71°
70°
69°
68°
67°
66°
65°
64°
44°
43°
42°
41°
40°
100 M
10 METRES
SURFACE
UP TO 1.0/m³
1.1 TO 3.0/m³
3.1 TO 10.0/m³

Fig. 2. Distribution of haddock eggs at the surface and 10 m, April 1956.

If, as seems likely, the vertical distribution of haddock eggs does not vary appreciably in time or space, it would be possible to obtain a reliable estimate of the relative abundance of haddock eggs between years from samples within the upper 20 m of the water column. Furthermore, if the relative abundance between stations in the depth stratum of maximum abundance was similar to that based on a sample of the whole water column, the horizontal distribution and thus the time and location of spawning could be determined from sampling a limited depth stratum. To test the feasibility of such an approach a comparison is made in Fig. 1 of the distribution of haddock eggs as determined from a sample of the whole water column and of the 0 - 22 m, 22 - 56 m, and 66 - 104 m depth strata during March, April, May and June, 1940.

In all cruises the relative abundance of eggs between stations in the shallow and second depth stratum was generally similar. The distribution of eggs in the shallow depth stratum was most representative of the distribution as determined from a sample of the whole water column.

One distinct advantage of confining sampling to a restricted depth zone is that once the depth and depth range of this stratum of maximum abundance is established for a particular species of egg a more rapid and thorough coverage of an area can be accomplished. This is not only desirable in studies of the timing of spawning, but because of the patchiness of the distribution of eggs it is also essential to obtain a maximum number of samples in order to delineate spawning locations accurately. A good illustration of the irregularity in the horizontal distribution of haddock eggs is afforded by the data collected during the Continuous Plankton Recorder surveys. The distribution of haddock eggs at the surface and 10 m during April 1956 is shown in Fig. 2.

## VERTICAL DISTRIBUTION AND BEHAVIOUR OF HADDOCK LARVAE AND PELAGIC JUVENILES

### 1. Vertical Distribution

There have been four surveys made in the Gulf of Maine - Georges Bank area in which quantitative samples were obtained in a form suitable for an analysis of the vertical distribution of larval and juvenile haddock. The first series of data was collected during the *Atlantis* cruises to Georges Bank during the springs of 1940 and 1941. The majority of haddock collected during these cruises were prolarvae and early postlarvae (average length - 4.7 mm and size range - 3.1 mm to 10.0 mm). The average number of larvae per cubic metre in the individual depth stratum for stations where tows were made at two levels and for stations where tows were made at three levels for individual cruises and the yearly average number per cubic metre and percentage of haddock larvae in individual depth stratum for 2 and 3 level stations are presented in Table 4.

The relative abundance of larvae in the three depth strata varied considerably between cruises. In both 1940 and 1941 and on individual cruises in which appreciable numbers of larvae were caught, the average abundance of larval haddock was greatest in the shallow stratum at both two and three level stations. At three level stations, the average abundance in the second and deep stratum was similar in 1940, but greater in the second stratum than in the deep stratum in 1941.

Decidedly fewer larval haddock than haddock eggs were collected during the Continuous Plankton Recorder surveys of the Gulf of Maine - Georges Bank area in the springs of 1953, 1955 and 1956 (average number of eggs per cubic metre - 0.106, average number of larvae per cubic metre - 0.018). The average length of the larvae collected at the surface and 10 m during these surveys was 9.2 mm and the range in length 3.1 mm to 40.0 mm. The average length of larvae caught at the surface (10.0 mm) was greater than the average length of larvae caught at 10 m (8.5 mm). The average abundance and percentage of larval haddock at the surface and 10 m for individual years and for the 3 years combined are presented in Table 5.

In 1953 and in 1956 larval haddock were more abundant at 10 m than at the surface, while in 1955 they were slightly more abundant at the surface. The percentage of larvae at 10 m was greatest in 1956, the only year in which appreciable numbers of larvae were caught. Although the 1940 - 41 data indicated that both haddock eggs and larvae were most abundant in the upper 20 m of the water column, the Continuous Plankton Recorder survey data indicated that, unlike haddock eggs, which showed a steady decrease in abundance with depth, the depth at which larval haddock are most abundant is well below the surface.

During May 1958, a cruise was undertaken with the objective of getting more detailed information

TABLE 4.—THE ABUNDANCE (NUMBER PER CUBIC METRE) AND PERCENTAGE OF HADDOCK LARVAE BY DEPTH STRATA AT TWO AND THREE LEVEL STATIONS, APRIL - JUNE, 1940 AND 1941

| | 1940 | | | | | |
|---|---|---|---|---|---|---|
| | *Atlantis* Cruise No: | 96 | 97 | 98 | Avg | Percent |
| | Date: | 17-27 April | 9-16 May | 1-8 June | | |
| 2 level stations | shallow 0 m - 22 m | 0.01 | 0.27 | 0.38 | 0.17 | 75 |
| | second depth 22 m - 56 m | 0.03 | 0.04 | 0.14 | 0.06 | 25 |
| 3 level stations | shallow 0 m - 22 m | 0 | 0.05 | 0.23 | 0.08 | 46 |
| | second depth 22 m - 56 m | 0.02 | 0.02 | 0.13 | 0.05 | 27 |
| | deep 66 m - 104 m | 0 | 0.01 | 0.15 | 0.05 | 27 |

| | 1941 | | | | | |
|---|---|---|---|---|---|---|
| | *Atlantis* Cruise No: | 113 | 114 | 115 | Avg | Percent |
| | Date: | 15-23 April | 7-14 May | 28 May 4 June | | |
| 2 level stations | shallow 0 m - 22 m | 0 | 0.13 | 0.48 | 0.21 | 54 |
| | second depth 22 m - 56 m | 0.01 | 0.17 | 0.34 | 0.18 | 46 |
| 3 level stations | shallow 0 m - 22 m | 0 | 0.03 | 0.42 | 0.15 | 62 |
| | second depth 22 m - 56 m | 0 | 0.02 | 0.21 | 0.08 | 32 |
| | deep 66 m - 104 m | 0 | 0.03 | 0.01 | 0.02 | 6 |

TABLE 5.—THE ABUNDANCE AND PERCENTAGE OF LARVAL HADDOCK AT THE SURFACE AND 10 M DURING 1953, 1955 AND 1956

| | 1953 | | 1955 | | 1956 | | Avg | |
|---|---|---|---|---|---|---|---|---|
| | No./m$^3$ | % | No./m$^3$ | % | No./m$^3$ | % | No./m$^3$ | % |
| Surface | .005 | 42 | .007 | 54 | .017 | 31 | .007 | 39 |
| 10 m | .007 | 58 | .006 | 46 | .063 | 69 | .011 | 61 |

on the depth distribution of postlarval haddock, employing multi-depth sampling techniques. Modified Hardy Plankton Samplers (Miller, 1961) were used and sampling took place at three stations in the Georges Bank area. Each station was occupied for 2 consecutive days. Thirty-minute horizontal tows at a speed of 7 knots were taken every 2 hours at depths of 1, 10, 20, 30, 40, 50 and 75 m. The average length of haddock larvae caught during this cruise was 9.0 mm and the range in length, 4.0 to 21.0 mm. A detailed analysis of these data has been made by Miller *et al* (1963). The abundance, percentage, and mean length of larval haddock caught at each depth at the three stations are listed in Table 6.

Although there was a variation in the depth of maximum abundance of larvae between stations and between size groups of larvae, at all stations over 80% of the larvae occurred between the 10-m and 40-m levels. The average "larval-depth" (determined by multiplying the number of larvae by the

TABLE 6.—THE ABUNDANCE, PERCENTAGE, AND MEAN LENGTH OF HADDOCK LARVAE BY DEPTH, MAY 1958

| | Station I | | | Station II | | | Station III | | |
|---|---|---|---|---|---|---|---|---|---|
| Depth | No./$m^3$ | % | Mean length | No./$m^3$ | % | Mean length | No./$m^3$ | % | Mean length |
| Surface | 0.046 | 4.2 | 10.4mm | 0.050 | 9.2 | 11.8mm | 0.017 | 2.7 | 10.6mm |
| 10 m | 0.267 | 24.3 | 8.6mm | 0.221 | 40.8 | 12.0mm | 0.114 | 18.1 | 9.0mm |
| 20 m | 0.218 | 19.8 | 7.2mm | 0.135 | 25.0 | 12.0mm | 0.386 | 38.6 | 8.8mm |
| 30 m | 0.277 | 25.1 | 6.6mm | 0.082 | 15.1 | 11.2mm | 0.202 | 31.9 | 9.5mm |
| 40 m | 0.187 | 17.0 | 6.7mm | | | | | | |
| 50 m | 0.106 | 9.6 | 6.8mm | 0.040 | 7.4 | 10.9mm | 0.055 | 8.7 | 9.6mm |
| 75 m | | | | 0.013 | 2.5 | 11.7mm | | | |

depth sampled, summing the weighted samples and dividing by the total larvae at all depths) was 25 m at Station I, 20 m at Station II, and 24 m at Station III. Larval haddock less than 8 mm in length were dispersed over a greater depth range than the larger larvae. The average larval depth for larvae smaller than 8 mm was 27 m. The data showed that over 80% of the haddock larvae in the 8 - 21 mm size range were concentrated within the depth range of the thermocline which occupied about 25% of the entire water column sampled.

Data on the vertical distribution of juvenile haddock were obtained on four cruises to the Gulf of Maine during the periods 25 July - 2 August and 5 - 11 September, 1957 and 28 July - 1 August and 9 - 16 September, 1958 (*Albatross III* Cruises 99, 102, 116 and 117) in connection with a study of the vertical distribution of redfish (Kelly and Barker, 1961). The sampling gear used was a 10-ft Isaacs-Kidd midwater trawl modified to operate as an opening and closing net. Consecutive 1-hour tows were made at a speed of 4.5 knots at depths of 10,20,30,40,60,80,100 and 110 m. A total of 366 haddock were caught in 1957 (average length - 92.6 mm, size range - 32 mm to 124 mm) and a total of 4,261 haddock were caught in 1958 (average length - 90.4 mm, size range - 27 mm to 121 mm). In Table 7 the number of tows, catch per tow and percentage of juvenile haddock by depth for the 1957, 1958 and total cruises are tabulated.

TABLE 7.—NUMBER OF TOWS AND ABUNDANCE AND PERCENTAGE OF JUVENILE HADDOCK BY DEPTH, JULY - SEPTEMBER, 1957 AND 1958

| | *Albatross III* Cruises 99&102 July - September 1957 | | | *Albatross III* Cruises 116&117 July - September 1958 | | | Total Cruises | | |
|---|---|---|---|---|---|---|---|---|---|
| Depth | No. of tows | Catch per tow | % | No. of tows | Catch per tow | % | No. of tows | Catch per tow | % |
| 10 m | 23 | 1.3 | 9.6 | 14 | 85.9 | 21.2 | 37 | 33.3 | 22.3 |
| 20 m | 35 | 7.1 | 52.2 | 15 | 118.1 | 29.2 | 50 | 40.4 | 27.1 |
| 30 m | 20 | 2.3 | 16.8 | 11 | 59.3 | 14.7 | 31 | 22.5 | 15.1 |
| 40 m | 21 | 0.8 | 5.9 | 10 | 44.3 | 11.0 | 31 | 14.8 | 9.9 |
| 60 m | 7 | 1.3 | 9.6 | 4 | 48.3 | 11.9 | 11 | 18.3 | 12.3 |
| 80 m | 6 | 0.8 | 5.9 | 4 | 48.5 | 12.0 | 10 | 19.9 | 13.3 |
| 100 m | 8 | 0 | 0 | | | | 8 | 0 | 0 |
| 110 m | 4 | 0 | 0 | | | | 4 | 0 | 0 |

In both 1957 and 1958 the greatest abundance of juvenile haddock occurred at 20 m, although the proportion of fish at this depth was greater in 1957 than in 1958. No juvenile haddock were found below 80 m. During all four cruises the thermocline extended from approximately 10 to 50 m (Kelly and Barker, 1961, Fig. 2, p. 227), and it was in this zone of rapid temperature change that the greatest numbers of juvenile haddock were caught. The average depth of juvenile haddock depth was 28 m in 1957 and 33 m in 1958. The average depth of juvenile haddock from July to September was greater than that of larval haddock in May as was the average depth of the thermocline. In 1957, 85% and in 1958, 76% of the juvenile haddock were found within the depth range of the thermocline. These percentages agree closely with those obtained in May 1958 for postlarval haddock.

In Fig. 3 the percentage of 10-mm length groups of juvenile haddock at each depth are plotted for the periods July - August, 1957 and 1958 (*Albatross III* Cruises 99 and 116) and September, 1957 and 1958 (*Albatross III* Cruises 102 and 117). The average length of juvenile haddock caught during July - August was 84 mm and during September was 99 mm. The average depths during all cruises for the eight length groups in order of increasing size were 31, 28, 32, 32, 33, 39, 37 and 30 m. With the exception of haddock larger than 79 mm in July - August, all length groups were concentrated between 10 and 40 m during both periods. During the July - August period the greatest percentage of juvenile haddock 80 mm and larger was at the 80 m level. Although appreciable numbers of haddock were caught in only one of the 10 tows made at this depth, the data for both periods indicate that there is an increase in the average depth and depth range with an increase in length. Further sampling incorporating high-speed simultaneous tows is needed to validate these data.

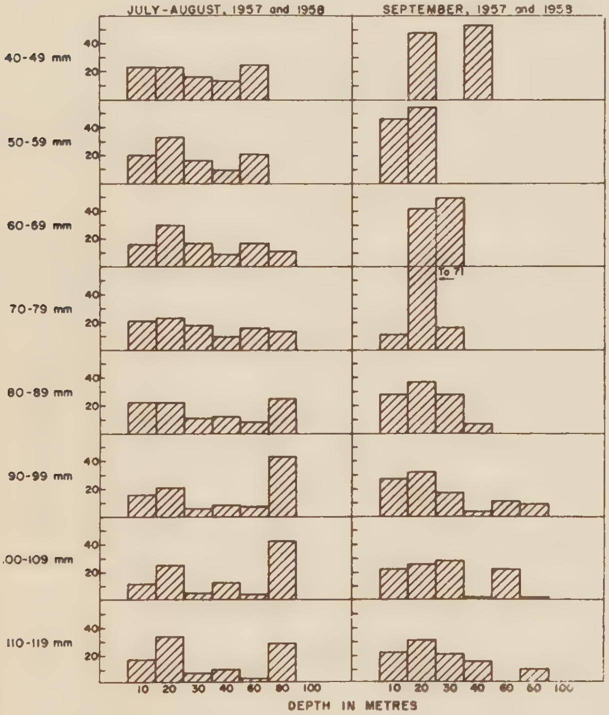


Fig. 3. The relative abundance in percent of 10 mm length groups of haddock by depth, July - August, 1957 and 1958 and September 1957 and 1958.

Vertical segregation has been observed for other species of larval and juvenile fish by many investigators (Russell, 1928; Silliman, 1943; Wiborg, 1948; and 1960; Sette, 1950; Ahlstrom, 1954, and 1959; Bridger, 1958; Kramer, 1960; Colton *et al.*, 1961; and Farris, 1961). The four series of observations in the Gulf of Maine - Georges Bank area demonstrate that prolarval, postlarval and juvenile haddock up to approximately 120 mm in length also tend to be concentrated within a narrow depth range. Over 90% of the prolarval and postlarval haddock (4.0 - 21.0 mm) occurred in the upper 40 m of the water column and over 80% of the postlarval haddock (8.0 - 21.0 mm) were concentrated within the thermocline. Although haddock larvae smaller than 8 mm were dispersed over a greater depth range than larvae larger than 8 mm, their average larval depth was only slightly greater. Wiborg (1960) found that in waters off the coast of Norway smaller cod larvae were also dispersed over a greater depth range and that there was an increase in depth stratification with an increase in length.

Over 75% of haddock up to 124 mm in length occurred between the 10- and 40-m levels, so that it appears that it would be possible to obtain a reliable estimate of the relative abundance of larval and juvenile haddock within a given area, between years, from a sample within a limited depth stratum. The depth range of maximum abundance of larval and juvenile haddock coincided with the depth range of the thermocline. The depth limits of the thermocline are readily definable and do not vary markedly with location in an area such as Georges Bank. These facts suggest that it would be possible to determine the horizontal distribution of these fish from a sample within this restricted depth zone.

## 2. Behaviour

There are two aspects of the behaviour of larval and juvenile fish, namely diurnal migration and escapement, that must be considered in any sampling program. Diurnal migrations, at least for many species of larval and juvenile fish, are not as extensive as once assumed (Johansen, 1925; Russell, 1928; and Sette, 1950), as it has been demonstrated that variations in the day and night catch are due in large part to the ability of many species to avoid slow-moving collecting nets (Silliman, 1943; Ahlstrom, 1954; Bridger, 1956 and 1958; and Colton and Marak, 1962). This ability to avoid capture increases with the size of the fish and the amount of light, with a resulting decrease in the catch and average size of fish caught in the surface layers during the day and an increase during the night. Bridger (1958) and Southward (1962) in experiments made with the Gulf III high-speed sampler have shown that a reduction in the shock wave that precedes the net and an increase in filtration efficiency are as important as high speed in preventing evasion by fast moving animals.

The data used in this report corroborate these findings. For example, the average size and range in size of haddock and cod larvae taken with the Continuous Plankton Recorder were considerably greater than the average size and range in size of haddock and cod larvae collected with 1-m nets on the same cruises or with Clarke-Bumpus Samplers during similar seasons (Colton and Marak, 1962). In addition, there was no consistent diurnal difference in the average number of larval haddock caught in the upper 10 m of the water column with the Continuous Plankton Recorder (54% in the day and 46% at night), while with both the metre net and Clarke-Bumpus Sampler many more larval haddock were caught during the night. More juvenile haddock were caught during the night at all depths except 80 m with the Isaacs-Kidd midwater trawl during 1957 and 1958. The average catch per tow of juvenile haddock for all depths during the day was 17.5 and during the night was 36.5. The night/day ratio in the catch tended to decrease with depth and increase with the length of fish. There was no significant difference at any depth in the abundance, average size/and size range of larval haddock, caught with the modified Hardy Plankton Samplers during the vertical distribution studies in May, 1958 (Miller *et al.*, 1963).

During both surveys in which there were no significant differences in day and night catch of haddock, high-speed samplers having a high ratio of effective filtering area to sampling aperture were used. The Continuous Plankton Recorder has a filtering ratio of 32 to 1 and the modified Hardy Plankton Sampler has a filtering ratio of 18 to 1. Both these ratios are much larger than those of the ordinary tow nets and thus assure a more rapid movement of water through the mouth of the gear.

There was no evidence of any diurnal change in the depth distribution of larval haddock in May 1958. The average larval depth at the three stations was 24 m during the day and 22 m during the night. The average depth of juvenile haddock caught with the Isaacs-Kidd trawl in 1957 and 1958, however, did show diurnal variation, being at 40 m during the day and at 30 m during the night. Considering that no juvenile haddock were found below 80 m during the day or night, that over twice as many juvenile haddock were caught during the night than during the day, and that the night/day ratio in the catch tended to decrease with depth, it would appear that this diurnal variation in depth distribution is an artifact resulting from increased daylight avoidance. In addition, simultaneous tows were not made with the Isaacs-Kidd trawl so that there was considerable variation in time and location between sampling depths. In neither series of data was there any evidence of a night-time migration of larvae or juveniles from depths below the maximum depth sampled. Such stability in the depth distribution of larval and juvenile fish has been observed in other species as well (Ahlstrom, 1959 and Farris, 1961).

## VERTICAL DISTRIBUTION AND BEHAVIOUR OF EARLY DEMERSAL STAGES OF HADDOCK

Census surveys of the groundfish populations in the Gulf of Maine - Georges Bank area were made in September 1955 (*Albatross III* cruises 65 and 66), November 1956 (*Albatross III* cruises 81 and 82), and October 1958 (*Albatross III* cruises 118, 119, and 120). One of the objectives of these surveys was to estimate the abundance of young-of-the-year haddock for predictions of year class strength. The survey gear was a standard otter trawl having a 1.3 cm mesh cotton liner in the cod end and upper belly. The towing speed was 2.5 knots, and all tows were 1/2 hour long from hook-up to haul-back.

An analysis of these data showed that the abundance of young-of-the-year and 1-year-old haddock fluctuated in the same way, both being high in all areas in 1955 and 1958 and low in 1956. This tendency towards a greater abundance of haddock in certain years was also manifest to a lesser degree in the survey catches of older haddock. For example, the catch per tow of haddock of all ages was greater in 1958 than in 1956. One consequence of this fluctuation in fishing efficiency between years is that estimates of year class strength are dependent upon what age fish are chosen to represent the year class and in what year the sampling was done. From these data the 1956 year class would appear much stronger on a basis of the abundance of 2-year-old haddock in 1958 than of the abundance of young-of-the-year haddock in 1956.

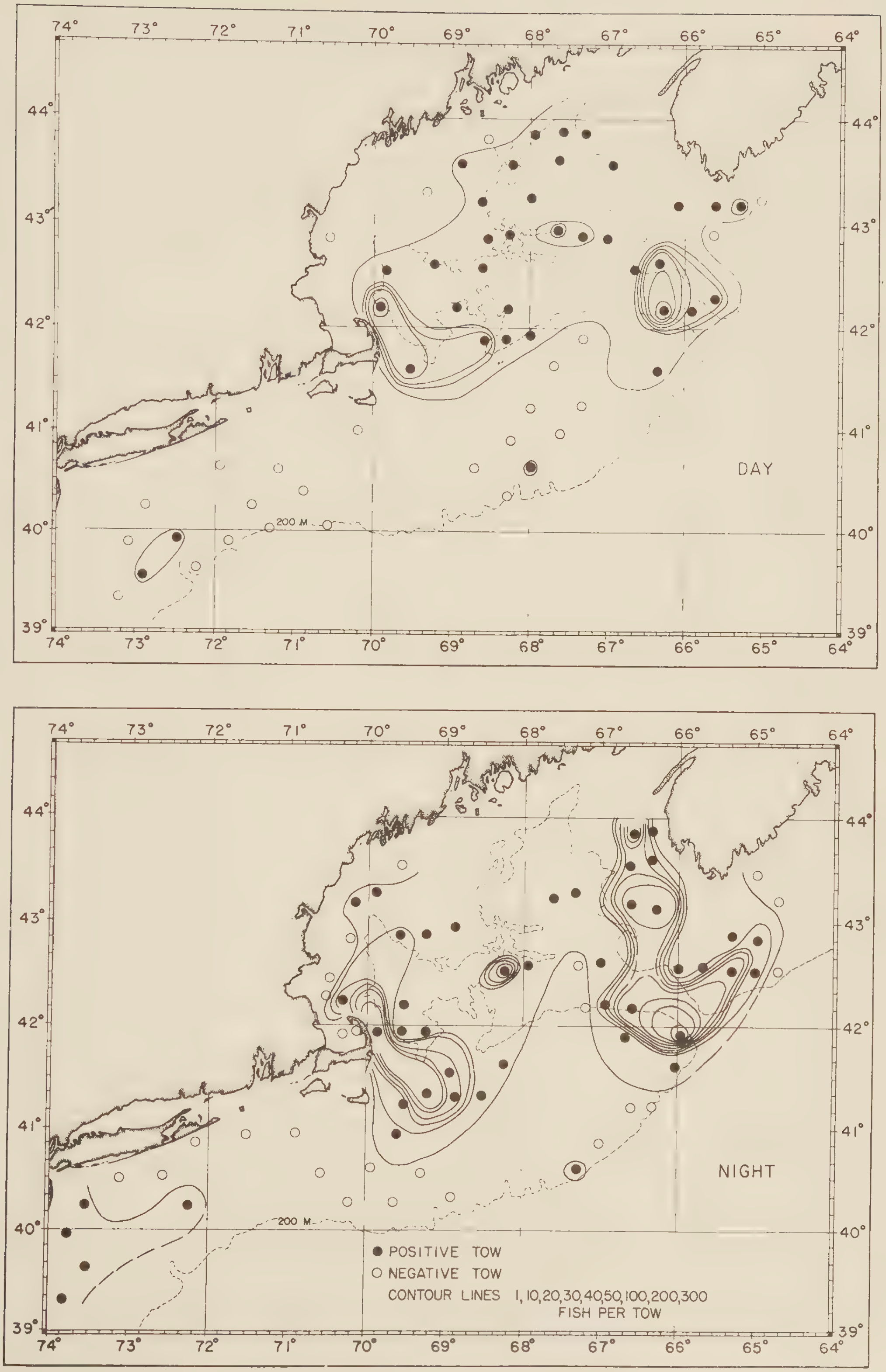
The gear, method of tow and area of coverage were similar during all survey cruises, so that it does not appear that the variation in fishing efficiency between years could be due to any differences in fishing technique. However, commercial vessels tend to catch more haddock during the day than during the night and this variation in the day and night catch is greatest in deeper water. If during the survey cruises, there had been a marked variation in the proportion of day and night tows, this could, conceivably, be the cause of the variation between years in fishing efficiency. To determine if such was in fact the case, a tabulation was made in Table 8 of the number of day and night tows and of the catch per tow of young-of-the-year, 1-year-old, and 2+ year haddock during the day and night for the three survey cruises. Young-of-the-year and 1-year-old haddock are tabulated separately, for it was for these ages that the most marked yearly variation in abundance were observed. The reason for the difference in the number of tows tabulated for young-of-the-year haddock and in the number of tows tabulated for 1-year-old and 2+ year haddock in 1955 and 1956 is that at some stations only young-of-the-year haddock were counted or young-of-the-year haddock were lost due to a tear in the fine mesh liner.

TABLE 8.—THE NUMBER OF TOWS AND THE CATCH PER TOW OF HADDOCK BY DAY AND NIGHT IN THE GULF OF MAINE - GEORGES BANK AREA, SEPTEMBER 1955, NOVEMBER 1956 AND OCTOBER 1958.

| | | Day (0730 - 1629) | | | Night (1930 - 0429) | | |
|---|---|---|---|---|---|---|---|
| | Year | No. of tows | No. of fish | C/T | No. of tows | No. of fish | C/T |
| Young-of-the year haddock | 1955 | 46 | 218 | 4.7 | 53 | 732 | 13.8 |
| | 1956 | 34 | 72 | 2.1 | 37 | 58 | 1.6 |
| | 1958 | 46 | 264 | 5.7 | 50 | 1216 | 24.3 |
| | Total | 126 | 554 | 4.4 | 140 | 2006 | 14.3 |
| One-year-old haddock | 1955 | 42 | 45 | 1.1 | 54 | 349 | 6.8 |
| | 1956 | 35 | 74 | 2.1 | 37 | 48 | 1.3 |
| | 1958 | 46 | 286 | 6.2 | 50 | 548 | 11.0 |
| | Total | 123 | 405 | 3.2 | 141 | 945 | 6.7 |
| 2+ year haddock | 1955 | 42 | 466 | 11.0 | 54 | 270 | 5.0 |
| | 1956 | 35 | 285 | 8.1 | 37 | 212 | 5.7 |
| | 1958 | 46 | 958 | 20.8 | 50 | 732 | 14.6 |
| | Total | 123 | 1709 | 13.9 | 141 | 1214 | 8.6 |

The day and night effort did not vary markedly, although in all years more tows were made during the night than during the day. The catch per tow of young-of-the-year haddock was slightly greater during the day in 1956 and much greater during the night in 1955 and 1958. The catch per tow of 1-year-old haddock was greater during the day in 1956 and greater during the night in 1955 and 1958. The average night/day ratio of abundance was greater for young-of-the-year haddock than for 1-year-old haddock. In all years the catch per tow of 2+ year haddock was greatest during the day as is the case in the commercial catch. The day/night ratio of abundance of 2+ year haddock was of the same order of magnitude during all years, but the abundance of young-of-the-year and 1-year-old haddock was only greater at night in the years when the survey cruises indicated that these two age groups were most abundant (1955 and 1958).

Year-class strength estimates based on the abundance of young-of-the-year haddock during both day and night would indicate that the 1955 and 1958 year classes were strong. The night time data would not only indicate that the 1955 and 1958 year classes were considerably stronger than indicated by the day time data, but that the 1958 year class was approximately twice as strong as the


74°
73°
72°
71°
70°
69°
68°
67°
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65°
64°
44°
43°
42°
41°
40°
39°
200 M
DAY
NIGHT
● POSITIVE TOW
○ NEGATIVE TOW
CONTOUR LINES 1, 10, 20, 30, 40, 50, 100, 200, 300 FISH PER TOW

Fig. 4. Distribution of young-of-the-year haddock during the day and night, October, 1958.

1955 year class. The day time catch of 1-year-old haddock would indicate that only the 1957 year class was strong, while the night time catch would indicate that both the 1957 and 1954 year classes were strong. Although not as marked, significant yearly differences in the relative abundance of 2+ year haddock also occurred between the day and night data.

Not only do estimates of abundance of haddock based on day and night observations vary, but also the distribution pattern is different if based on night observations than if based on day observations. This is demonstrated in Fig. 4 showing the distribution of young-of-the-year haddock as determined during the day and night tows in October, 1958. Young-of-the-year haddock were found over a much wider area at night and also areas of high abundance (off southeastern Nova Scotia) were not indicated by the day time data.

When the 3-year average catch per tow of young-of-the-year, 1-year-old and 2+ year haddock was determined for hourly intervals, the plots showed marked hourly fluctuations in the abundance of all age groups. Although in general the catch per tow of young-of-the-year and one-year-old haddock tended to be higher during the night time hours and the catch per tow of 2+ year haddock tended to be higher during the daylight hours, the fluctuations in the number of fish caught, between individual tows within a given hour, were too great to attach any significance to the abundance figures. The main cause for these fluctuations appears to be the marked regional variations in the abundance of haddock. Obviously there were many tows made during the night in areas where there were few or no young-of-the-year and 1-year-old haddock, or many 2+ year haddock, and tows made during the day where the reverse situation existed. In any event, the day/night variability in the catch is real, but special sampling programs in which tows are made at set time intervals within relatively small areas for an appreciable number of days are needed before this variability can be accurately assesse

Diurnal migration appears to be the cause of the variation in the day and night catch of 2+ year haddock. Although no sampling has been undertaken to determine if haddock move off the bottom during the night, trawling experiments and echo sounder observations have shown that haddock move off the bottom at night in other areas (Woodhead, 1961). Indications are that this is also the case in the Gulf of Maine - Georges Bank area where the commercial catch of haddock is greater during the day tha at night. Diurnal migration cannot explain the variation in the day and night catch of young-of-the-year and 1-year-old haddock unless, unlike older haddock, these young fish move up in the day and dow at night. It is also possible that young-of-the-year and 1-year-old haddock do not move off the bottom at night. However, observations on the diurnal migration of herring in the North Sea (Lucas, 1936) and of haddock in the Barents Sea (Woodhead, 1961) have demonstrated that smaller fish show more tendency to leave the sea bed than do larger fish. It appears that the day time decrease in the catch of young-of-the-year and 1-year-old haddock is due to a variation in the catching efficiency of the otter trawl between day and night. This variation in catching efficiency could be due either to an increase in the avoidance of the trawl during the day, as has been demonstrated in the case of larval and juvenile fish, or to an increase in escape through the unlined meshes of the trawl wings (12.7 cm stretched mesh) during the day. No doubt haddock of all ages are able to avoid the otter trawl to some extent, but it appears that the younger fish may exhibit a more rapid visual and auditory response to the trawl and that the day and night variability in the catch of young-of-the-year and 1-year-old haddock due to avoidance or escapement is greater than that due to vertical migration

There would appear to be only two possible methods of increasing the daytime catching efficiency of the otter trawl. One would be to increase the towing speed, but this does not appear practical for it is difficult to keep the trawl on the bottom at high speed and the amount of backwash and turbulence at the mouth of the net would be increased. Another, and possibly more effective way of reducing escape, would be to decrease the mesh size of the trawl wings. It appears quite possible that all age haddock enter the net at the same rate, but the smaller fish (young-of-the-year and 1-year-olds) are able to escape through the meshes of the wings and are better able to do this during the day than during the night. In order to determine if this is in fact the case, it would be necessary to make a duplicate series of tows during the day and night with and without a fine mesh liner in the wings.

It is evident that one of the causes of the variability in fishing efficiency between years is the diurnal variation in the catch. If the various age haddock were randomly distributed and if the diurnal cycle was similar for all age haddock and for all depths, due allowance could be made for this diurnal variation. However, in addition to the variance caused by day and night differences in depth distribution there is apparently also bias caused by a variation in the fishing efficiency of the otter trawl with age of fish and time of day. Until this variance is allowed for and the bias eliminated, the relative abundance of haddock between areas and years can only be made for a specific age group and on a basis of data collected either by day or night.

## SUMMARY AND CONCLUSIONS

The analysis of the data on the vertical distribution of haddock eggs collected in 1931, 1932,
940, 1941, 1953, 1955 and 1956 in the Gulf of Maine - Georges Bank area demonstrated that, although
addock eggs occurred throughout the water column, eggs in all stages of development were concen-
rated in the surface layers and there was a decrease in abundance with an increase in depth. The
elative abundance of haddock eggs in the upper 20 m of the water column was similar to the relative
bundance of eggs based on a sample of the whole water column.

Surveys made in 1940, 1941, 1953, 1955, 1956 and 1958, in which quantitative data on the vertical
istribution of prolarval and postlarval haddock were obtained, demonstrated that haddock up to 21 mm
n length were concentrated within a limited depth stratum, the depth limits of which were defined by
he thermocline. At stations in which simultaneous samples were taken at depths down to 75 m over
0% of the larvae were found between the 10-and 40-m levels and within the thermocline.

In studies of the vertical distribution of juvenile haddock conducted in 1957 and 1958 in which
amples were taken at specific depths down to 110 m, over 75% of haddock, ranging in length from
7 mm to 124 mm, occurred between depths of 10 and 40 m and within the thermocline. No juvenile
addock of this size range were found at depths greater than 80 m.

In surveys in which high-speed samplers having a high ratio of effective filtering area to sam-
ling aperture were used, there were no significant differences in the day and night catch of larval
nd juvenile haddock and no variation in the depth distribution between day and night.

It appears that not only would it be possible to obtain a reliable estimate of the relative
bundance of the eggs, larvae, and pelagic juveniles of haddock as well as other species on a basis
f samples confined to a limited depth stratum, but also that the areal distribution and thus the time
nd location of spawning and the drift and migrations of larval and juvenile fish could be obtained by
ampling a restricted depth stratum.

In studies of the early life history and year-class strength fluctuations of most species of mar-
ne fish it does not seem feasible or expedient to attempt to determine the absolute abundance of eggs
nd larvae. Indeed, no conclusive correlation has been demonstrated between the abundance of eggs and
arvae and the brood strength of these fish as measured by their contribution to the fishery in suc-
eeding years (Thompson, 1929*a* and 1929*b*; Poulsen, 1931 and 1941; Heegard, 1947; Carruthers *et al.*,
951; Rae, 1953; and Radovich, 1962). The time and location of spawning and the subsequent disper-
al of larvae and juveniles are likely to have greater influence on brood strength than the absolute
umber of eggs or larvae produced. The data on the vertical distribution of haddock eggs, larvae,
nd juveniles indicates that such information can be obtained from samples taken within a relatively
arrow depth zone. Because sampling of a limited depth stratum would be more rapid than sampling the
hole water column, a greater number of samples could be obtained in a given period. Reliable esti-
ates of abundance over broad geographical areas would be possible and more accurate data obtained
n the fluctuations in abundance in time and space.

To define the vertical distribution of the eggs or larvae of any species of fish it would be
dvisable to use high-speed, simultaneous, horizontal tows. Once the vertical distribution is ascer-
ained, it would be expedient to make high-speed oblique tows with samplers of high filtering capa-
ity to eliminate avoidance and to insure adequate samples. The studies of Bridger (1956, 1958) and
f Southward (1962) show that with modifications the Gulf III high-speed sampler (Gehringer, 1952)
s ideally suited for this purpose. A simple closing mechanism for this sampler has been described
y Kinzer (1962).

The analysis of data on the distribution and abundance of haddock during otter trawl surveys of
roundfish populations in the Gulf of Maine - Georges Bank area in 1955, 1956 and 1958 showed that
he catch of young-of-the-year and 1-year-old haddock fluctuated in the same way, both being high in
11 areas in 1955 and 1958 and low in 1956. The variation in abundance between years appears to re-
ult from a decrease in fishing efficiency during daylight hours, for the average catch per tow of
oung-of-the-year and 1-year-old haddock was markedly greater during the night than during the day
n years when the abundance figures were high. This day and night variation in the catch of young
addock is opposite to that of 2+ year haddock, the catch of which was greater during the day in all
ears as is the case in the commercial catch. The variation in the catch of young-of-the-year and
-year-old haddock is not due to a change in availability resulting from a movement off the bottom

during the night as in the case of 2+ year haddock, but appears to be due either to an increase in avoidance or escape through the trawl wings during the day. Special sampling programs are needed to determine the cause and to assess accurately the degree of this day and night variation in the catch. Regardless of the cause, the effect is real in that there are marked differences in abundance and distribution as determined from day and night observations.

This analysis of the catch of haddock eggs, larvae and juveniles shows that in studies of the early life history and brood strength fluctuations of fish we have to deal with populations of such complexity that special investigations on the nature of the distribution of the various developmental stages should be undertaken to improve sampling programs and the design of collecting gear with a view of minimizing variance and eliminating bias.

## REFERENCES

AHLSTROM, E.H. 1954. Distribution and abundance of egg and larval populations of the Pacific sardine. *Fish. Bull., U.S.* 56: (93): 83-140.

1959. Vertical distribution of pelagic fish eggs and larvae off California and Baja California. *Fish. Bull., U.S.* 60(161): 107-146.

BRIDGER, J.P. 1956. On day and night variation in catches of fish larvae. *J. Cons. int. Explor. Mer*, 22 (1): 42-57.

1958. On efficiency tests made with a modified Gulf III high-speed tow-net. *J. Cons. int. Explor. Mer*, 23(3): 357-365.

CARRUTHERS, J.N. *et al.* 1951. Variations in brood-strength in the North Sea haddock, in light of relevant wind conditions. *Nature*, 168 (4269): 317-319.

CLARKE, G.L. , E.L. PIERCE, and D.F. BUMPUS. 1943. The distribution and reproduction of *Sagitta elegans* on Georges Bank in relation to hydrographical conditions. *Biol. Bull.*, 85(3): 201-226.

CLARKE, G.L. and D.F. BUMPUS. 1950. The plankton sampler -- An instrument for quantitative plankton investigations. *Am. Soc. Limnol. and Oceanog., Spec. Pub.*, 5: 1-8. Revised.

COLTON, J.B., K.A. HONEY, and R.F. TEMPLE. The effectiveness of sampling methods used to study the distribution of larval herring in the Gulf of Maine. *J. Cons. int. Explor. Mer*, 26 (2): 180-190.

COLTON, J.B. and R.R. MARAK. 1962. Use of the Hardy Continuous Plankton Recorder in a fishery research programme. *Bull. Mar. Ecol.*, 5 (49): 231-246.

FARRIS, D.A. 1961. Abundance and distribution of eggs and larvae and survival of larvae of jack mackerel (*Trachurus symmetricus*). *Fish. Bull. U.S.*, 61 (187): 247-279.

GEHRINGER, J.W. 1952. 2. An all metal plankton sampler (Model Gulf III). *Spec. sci. Rep. U.S. Fish Wildl. Serv. - Fish.*, No. 88, p. 7-12.

HEEGAARD, P. 1947. Investigations of the breeding season and the quantities of eggs of the food fishes of the Kattegat and the northern Belt Sea 1929-1941. *Medd. Komm. Danm. Fisk. Havundersøg.*, 11(4): 1-20.

JOHANSEN, A.C. 1925. On the diurnal movements of young of some fishes in Danish waters. *Medd. Komm. Danm. Fisk. Havundersøg.*, 8(2): 1-27.

KELLY, G.F. and A.M. BARKER. 1961. Vertical distribution of young redfish in the Gulf of Maine. *Rapp. et Proc.-Verb.*, 150: 220-233.

KINZER, J. 1962. Ein einfacher Schiessmechanismus für die Planktonröhre "Hai" (A simple closing mechanism for a modified Gulf III plankton sampler). *Kurze Mitteilungen aus dem Institut für Fiskereibiologie der Universität Hamburg*, No. 12, Dec., 1962: 13-17.

KRAMER, D. 1960. Development of eggs and larvae of Pacific mackerel and distribution and abundance of larvae 1952-56. *Fish. Bull., U.S.*, 60 (174): 393-438.

LUCAS, C.E. 1936. On the diurnal variation of size-groups of trawl-caught herring. *J. Cons. int. Explor. Mer*, 11 (1): 53-59.

MILLER, D. 1961. A modification of the small Hardy plankton sampler for simultaneous high-speed plankton hauls. *Bull. Mar. Ecol.*, 5 (45): 165-172.

MILLER, D., J.B. COLTON, and R.R. MARAK, 1963. A study of the vertical distribution of larval haddock. *J. Cons. int. Explor. Mer*, 28 (1): 37-49.

POULSEN, E.M. 1931. Biological investigations upon the cod in Danish waters. *Medd. Komm. Danm. Fisk. Havundersøg.*, 9 (1): 1-148.

1941. On fluctuations in the size of the stock of cod in the waters within the Skaw during recent years. *Rept. Danish Biol. Sta.*, 46: 1-36.

RADOVICH, J. 1962. Effects of sardine spawning stock size and environment on year class production. *Calif. Fish Game*, 48(2): 123-140.

RAE, B.B. 1953. The occurrence of lemon sole larvae in the Scottish plankton collections of 1929, 1930, and 1931. *Mar. Res. Scot.*, 1953, No. 1: 1-36.

RUSSELL, F.S. 1928. The vertical distribution of marine macroplankton. VIII. Further observations on the diurnal behaviour of the pelagic young of teleostean fishes in the Plymouth area. *J. Mar. Biol. Ass., U.K.*, 15 (3): 829-850.

SETTE, O.E. 1950. Biology of the Atlantic mackerel (*Scomber scombrus*) of North America Part I: Early life history, including growth, drift, and mortality of the egg and larval populations. *Fish. Bull., U.S.*, 50 (38): 149-237.

SILLIMAN, R.P. 1943. Thermal and diurnal changes in the vertical distribution of eggs and larvae of the pilchard (*Sardinops caerulea*). *J. Mar. Res.*, 5 (2): 118-130.

SOUTHWARD, A.J. 1962. The distribution of some plankton animals in the English Channel and approaches. II. Surveys with the Gulf III high-speed sampler, 1958-60. *J. Mar. Biol. Ass., U.K.*, 42 (2): 275-375.

THOMPSON, H. 1929*a*. 2. Haddock biology (North Sea). A brief survey of recent data, methods and results. *Rapp. et Proc.-Verb.*, 54: 135-163.

1929*b*. General features in the biology of the haddock (*Gadus aeglefinus* L.) in Icelandic waters in the period 1903-1926. *Rapp. et Proc.-Verb.* 57: 1-73.

WALFORD, L.A. 1950. Effects of currents on distribution and survival of the eggs and larvae of haddock (*Melanogrammus aeglefinus*) on Georges Bank. *Fish. Bull., U.S.*, 49 (29): 1-73.

WIBORG, K.F. 1948. Investigations on cod larvae in the coastal waters of Northern Norway. Occurrence of cod larvae, and occurrence of food organisms in the stomach contents and in the sea. *Fiskeridir. Skr. Havundersøk.*, 9 (3): 1-27.

1960. Investigations on eggs and larvae of commercial fishes in Norwegian coastal and offshore waters in 1957-58. *Fiskeridir. Skr. Havundersøk.*, 12 (7): 5-27.

WOODHEAD, P.M.J. 1961. Diurnal variation in the trawl catches of haddock. *Cons. int. Explor. Mer, Comparative Fishing Committee*, No. 71: 1-5. (unpublished manuscript).

# EARLY DEVELOPMENTAL STAGES OF THE ROCK SHRIMP, *SICYONIA BREVIROSTRIS* STIMPSON, REARED IN THE LABORATORY[1]

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## ABSTRACT

Five nauplial, three protozoeal, four mysis, and the first postlarval stages of the rock shrimp, *Sicyonia brevirostris* Stimpson, reared from eggs spawned in the laboratory, are described and illustrated.

## I. INTRODUCTION

Fishery scientists at the Bureau of Commercial Fisheries Biological Laboratory in Galveston, Texas are studying the early life histories of Gulf of Mexico Penaeidae as part of an overall effort to establish relationships between the oceanic environment and the populations of commercially important shrimps. The effects of such variables as

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temperature, salinity, and circulation, as well as the success of spawning, cannot be accurately assessed until specific identification of the various larvae is possible. The larvae of penaeid shrimps, especially during the naupliar stage, are remarkably similar, and at least 13 penaeid species occur in the northwestern Gulf of Mexico. To insure accurate identification of those larvae belonging to the genus *Penaeus,* the group of primary importance, we must also be able to distinguish the larval stages of associated noncommercial penaeids. This report describes the early development stages of one of these species, *Sicyonia brevirostris* Stimpson.

According to Lunz (1957), *S. brevirostris* occurs on the continental shelf of the western Atlantic from just south of Norfolk, Virginia, around the Gulf of Mexico to Yucatan. It appears to be confined inside the 50-fathom contour, reaching greatest abundance at 35 to 40 fathoms. At points throughout its range, this shrimp occurs in considerable numbers. It is not fished commercially, but since it has a very agreeable taste and attains a relatively large size, it is generally regarded as having potential commercial value.

## II. Methods and Materials

All descriptions and figures are from specimens reared in the laboratory. Gravid females were caught at sea and transported to the laboratory. Spawning took place in a fiberglass aquarium that contained 80 liters of aerated, noncirculating sea water. The larvae were then maintained in the aquarium until the first postlarval stage was reached. Cultures of a diatom, *Skeletonema* sp., were added as food at the first protozoeal stage and brine shrimp, *Artemia* sp., were introduced at the first mysis stage.

Temperatures during rearing varied between 21.0° and 24.6° C. Salinity, which was 24.5‰ at the start, rose to a maximum of 27.4‰. The pH varied from 8.06 to 8.20.

Samples of larvae to be used for descriptive purposes were taken periodically and preserved in 5% buffered formalin. The unstained larvae were illustrated with the aid of a Camera Lucida. Dissection of the appendages was performed in formalin on a plastic slide.

The figures illustrating each substage depict an average larva. With the exception of the nauplial and protozoeal antennae, the appendages on these figures are intended to show only relative size and position, not setation or segmentation. To illustrate morphological details that would otherwise be obscured, we rotated the antennae of the nauplial substages on their axes. Figures of the mouth parts and other appendages represent a single appendage taken from one individual. In order to present a clearer figure, the setules on the setae were usually omitted. Measurements are given in mm.

The following abbreviations are used in the text: TL = total length, including the rostrum but excluding the caudal spines; W = mean width at the point of greatest width; CL = carapace length, including the rostrum; N = number of specimens.

The adult from which the larvae were obtained was identified according to Anderson and Lindner (1943) and Lunz (1945). Both the adult and the larvae have been deposited in the museum of the Bureau of Commercial Fisheries Biological Laboratory, Galveston, Texas.

## III. Description of Stages

### A. *Egg* (Fig. 1)

Viable eggs of *S. brevirostris* are round, golden brown in color, and translucent. Eggs measured soon after spawning were 0.23 mm in diameter. As the nauplius developed within the egg, the diameter increased to 0.27 mm just prior to hatching.

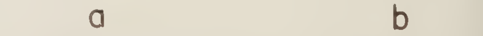


Figure 1. Late eggs showing developing nauplii. a. lateral view b. ventral view.

Hatching was observed only once. The nauplius filled the egg case and the furcal spines were already protruding when it was first noted. The nauplius appeared to flex, straightening out the first and second appendages and pushing the eggshell off the anterior end of its body.

### B. *Nauplius I* (Fig. 2)

Mean TL = 0.30 mm (0.28-0.32 mm);
W = 0.17 mm; N = 10

Nauplii of *S. brevirostris* exhibit the pyriform body that is typical of all penaeid larvae thus far described. A blunt labrum is present on the ventral surface and a slight protuberance arises from the dorsal surface of the body.

An ocellus, which is retained in subsequent nauplial substages, lies on the longitudinal axis of the body near the anterior end.

The posterior end of the body is rounded and bears a pair of spines.

Three pairs of appendages arise from the anterior portion of the body. The anterior ones (first antennae) are unbranched. The middle pair (second antennae) and third pair (mandibles) are branched into ventral endopods and dorsal exopods.

Setae arising from the appendages are smooth, but in succeeding substages the longer ones become plumose.

Color of the body and appendages is golden brown. The ocellus is black. Notes on color were not made for succeeding stages.

Setation of appendages:

First Antenna: Two short ventrolateral; a short spike and two long terminal; one long dorsolateral.

Second Antenna:

Endopod: Two short ventrolateral; two long terminal.

Exopod: Three long ventrolateral; two long terminal.

Mandible: Both branches bear three long setae.

### C. *Nauplius II* (Fig. 3)

Mean TL = 0.31 mm (0.29-0.34 mm);
W = 0.18 mm; N = 7

The body is slightly more elongate than in the preceding substage. The posterior portion (edge) of the body between the single pair of caudal spines becomes flattened.

Setation of appendages:

First Antenna: Two short ventrolateral; one short, one long, and one medium terminal; one short dorsolateral.

Second Antenna:

Endopod: Two short ventrolateral; two long terminal.

Exopod: Three long ventrolateral; two long and one short terminal.

Mandible: Unchanged from Nauplius I.

### D. *Nauplius III* (Fig. 4)

Mean TL = 0.35 mm (0.32-0.37 mm);
W = 0.18 mm; N = 26

The body is more elongate than in Nauplius II. Faint folds, the beginnings of ventral appendages, can be seen posterior to the labrum. The bases of the mandibles have become slightly swollen. A depression is present between the three pairs of caudal spines.

Setation of appendages:

First Antenna: One short and two medium ventrolateral; one medium, one long, and one short terminal.

Second Antenna:

Endopod: Two short ventrolateral; one short and two long terminal.

Exopod: Four long ventrolateral; two long and one short terminal.

Mandible: Unchanged from Nauplius I.

### E. *Nauplius IV* (Fig. 5)

Mean TL = 0.37 mm (0.33-0.40 mm);
W = 0.18 mm; N = 30

The body has become longer and the posterior portion more slender. The ventral appendages that were first noted in the preceding substage are more prominent, though still beneath the cuticle. These are the first and second maxillae and first and second maxillipeds. Two definite lobes have been formed at the posterior end of the body, each bearing five caudal spines.

Setation of appendages:

First Antenna: Two long and one medium ventrolateral; two long and one short terminal; one short dorsolateral.

Second Antenna:

Endopod: Two short ventrolateral; one long and two medium terminal.

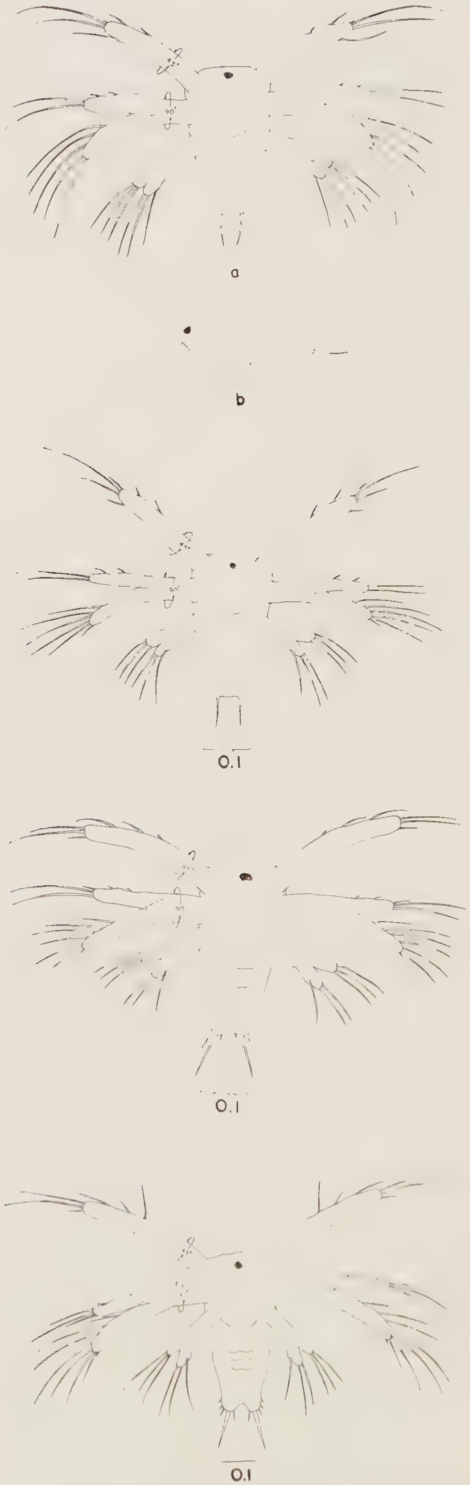
Exopod: One medium and three long ventrolateral; two long, one medium, and one short terminal.

Mandible: Unchanged from Nauplius I.

### F. *Nauplius V* (Fig. 6)

Mean TL = 0.44 mm (0.38-0.46 mm);
W = 0.18 mm; N = 46

The body is further elongated and the furcal processes are more pronounced, each giving rise to seven spines. The maxillae and maxillipeds are now external, and show more advanced development. The swelling at the base of the mandible, which has become large and prominent, possesses a masticatory surface composed of several rows of small teeth. Both the endopod and exopod of the mandible are frequently hollow and transparent. The outline of a developing carapace



Figures 2-5, top to bottom. 2. Nauplius I. a. ventral view b. lateral view. 3. Nauplius II, ventral view. 4. Nauplius III, ventral view. 5. Nauplius IV, ventral view.

can be seen on the dorsal surface of the body, and frontal organs are present on its anterior margin.

Setation of appendages:

First Antenna: Two short and one medium ventrolateral; two long, one medium, and two short terminal; two short dorsolateral.

Second Antenna:

Basis: One short ventrolateral.

Endopod: Two medium and two short ventrolateral; one short and three long terminal.

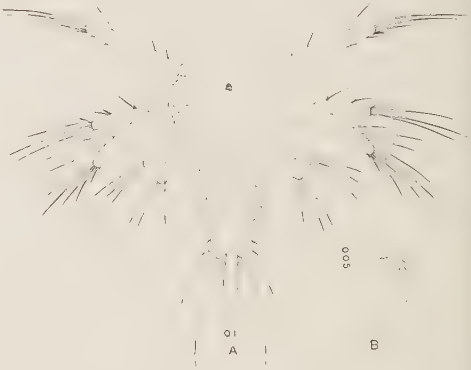


Figure 6. Nauplius V. A. ventral view B. base of mandible.

Exopod: Four long ventrolateral; three long, one medium, and one short terminal.

Mandible: Unchanged from Nauplius I.

G. *Protozoea I* (Fig. 7)

Mean TL = 0.81 mm (0.70-0.99 mm);
mean CL = 0.33 mm (0.30-0.36 mm);
N = 39

Body shape changes considerably with the molt to the first protozoeal substage. A large, loose-fitting carapace covers the anterior section of the body. The posterior portion of the body has lengthened greatly and is now distinctly segmented. The maxillae and first and second maxillipeds are well developed and functional.

The carapace is rounded with a median notch at the anterior end, a pair of rounded frontal organs being the only protuberances on it. The ocellus, which persists in subsequent protozoeal substages, is present between a pair of compound eyes that are visible beneath the carapace. The labrum does not bear a spine on its anterior margin. Two lobes of the labium, bearing short bristles on their inner margins, can be seen posterior to the labrum. Several teeth of the inwardly projecting mandibles can be seen between the labrum and labium.

The first antenna is approximately twice the length of the endopod of the second antenna. It is composed of three major segments. The basal segment, which is divided into five subsegments, bears one short seta. The second segment bears three setae, one short and one medium ventrolateral, and one short posterolateral. The disal segment bears three long and two short terminal, and one short posterolateral, setae.

The second antenna is composed of a two-segmented protopod, an endopod of two segments, and an exopod of from seven to nine, frequently indistinct, segments. The protopod bears one seta at the juncture with the endopod. The first segment of the endo-

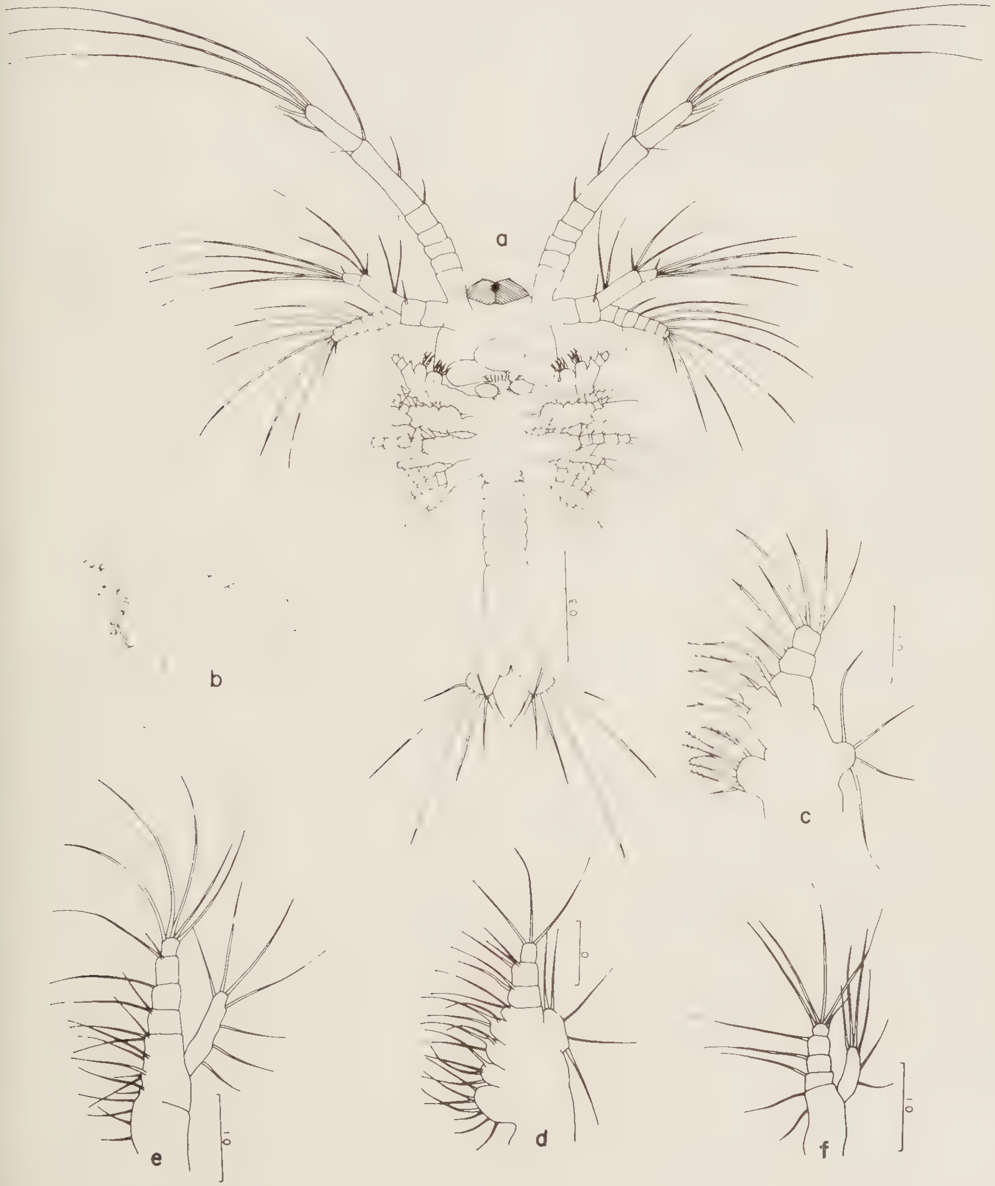


Figure 7. Protozoea I.

**a.** Ventral view
**b.** Mandible
**c.** Maxilla I
**d.** Maxilla II
**e.** Maxilliped I
**f.** Maxilliped II

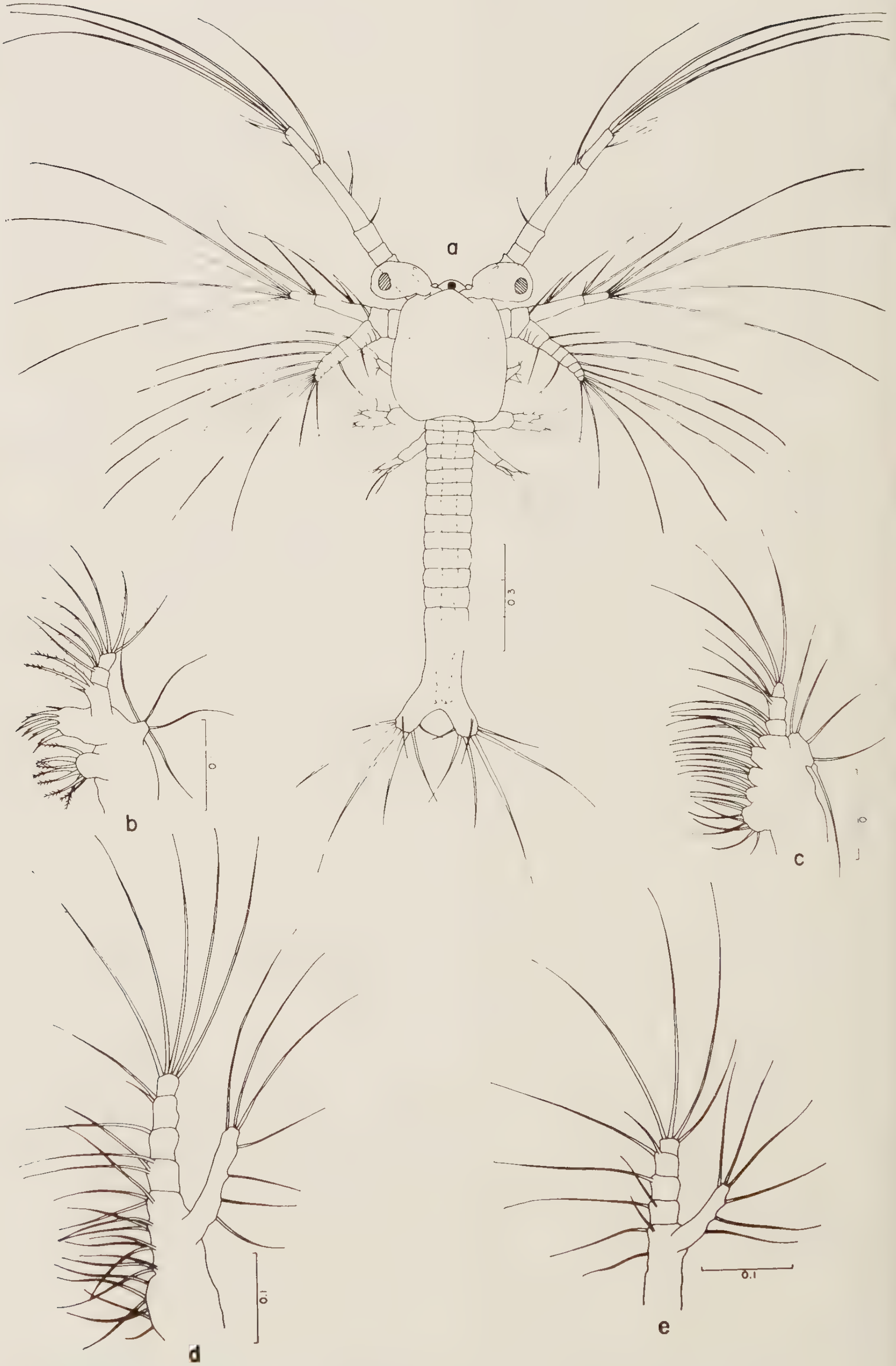


Figure 8. Protozea II.

**a.** Dorsal view
**b.** Maxilla I
**c.** Maxilla II
**d.** Maxilliped I
**e.** Maxilliped II

pod gives rise to a pair of setae from a point about one-third the length of the segment, and three terminal setae. The distal segment bears five terminal setae. The exopod bears five setae on its ventrolateral and two on its dorsolateral margins, as well as five terminal setae.

The mandible has lost both the endopod and exopod. The masticatory process is longer than in the last nauplial substage and curves inward, terminating in a ring of teeth.

The first maxilla consists of an unsegmented protopod, a three-segmented endopod, and a small knoblike exopod. The protopod has two large lobes, each giving rise to several stout, toothed spines. The first and second segments of the endopod each bear two setae, and the third five. The exopod bears four setae.

The second maxilla is comprised of an unsegmented protopod, a three-segmented endopod and a small knoblike exopod. The protopod has five lobes on its ventral margin, the basal lobe bears about seven setae and the remainder two to five. The first segment of the endopod bears two setae, the second and third, three; the exopod bears five.

The first maxilliped is longer than the maxillae and is biramous. It is composed of an unsegmented protopod, a four-segmented endopod, and an unsegmented exopod. The protopod has from 13 to 15 setae on its ventral margin. The first and third segments of the endopod each bear two setae; the second, one; and the fourth, five. The exopod bears four lateral and three terminal setae.

The second maxilliped greatly resembles the first, although it is somewhat smaller. The protopod bears two setae. The first three segments of the endopod each bear one seta and the fourth bears five. The exopod has three lateral and three terminal setae.

The third maxilliped is small, biramous, and usually does not bear setae.

The slender posterior portion of the body is divided into six thoracic segments and an unsegmented abdomen. The abdomen terminates in a well-developed, forked, telson, each lobe of which bears seven spines, the outermost etxending inward across the furca.

### H. *Protozoea II* (Fig. 8)

Mean TL = 1.23 mm (1.12-1.44 mm);
mean CL = 0.44 mm (0.38-0.45 mm);
N = 28

The second protozoea is characterized by the presence of stalked compound eyes, a segmented abdomen, and a small rostrum which does not extend to the anterior edge of the body.

The frontal organs have been lost and do not reappear in later substages. Small papillae which are present on the dorsoanterior margins of the eyes persist in the third protozoeal substage.

Segmentation of the appendages remains almost unchanged from the preceding substage. A dorsolateral seta has been added to the terminal segment of the first antenna. The number of spines on the second lobe of the protopod of the first maxilla has increased and an additional short seta is found on both the first and second segments of the endopod. Three setae have been added to the second maxilliped, one on the protopod and two on the endopod. Rudiments of five pairs of pereiopods are present posterior to the maxillipeds.

The abdomen is divided into six segments with the telson still part of the sixth. The number of caudal spines remains constant at seven pairs.

### I. *Protozoea III* (Fig. 9)

Mean TL = 1.96 mm (1.84-2.09 mm);
mean CL = 0.58 mm (0.54-0.61 mm);
N = 20

This substage can be distinguished from the second protozoea by the presence of biramous uropods and spines on the abdominal segments.

The rostrum has undergone slight elongation and now extends slightly past the anterior margin of the body.

The five subsegments which made up the basal segment of the first antenna in preceding protozoeal substages have combined and three are now four segments. The first segment gives rise to one seta; the second and third, two; and the fourth, seven. In addition to the two more prominent setae, a variable number of small setae now rim the distal portion of the third segment.

The second antenna, maxillae, and second and third maxillipeds remain essentially the same as in the preceding substage. The seta on the second segment of the endopod of

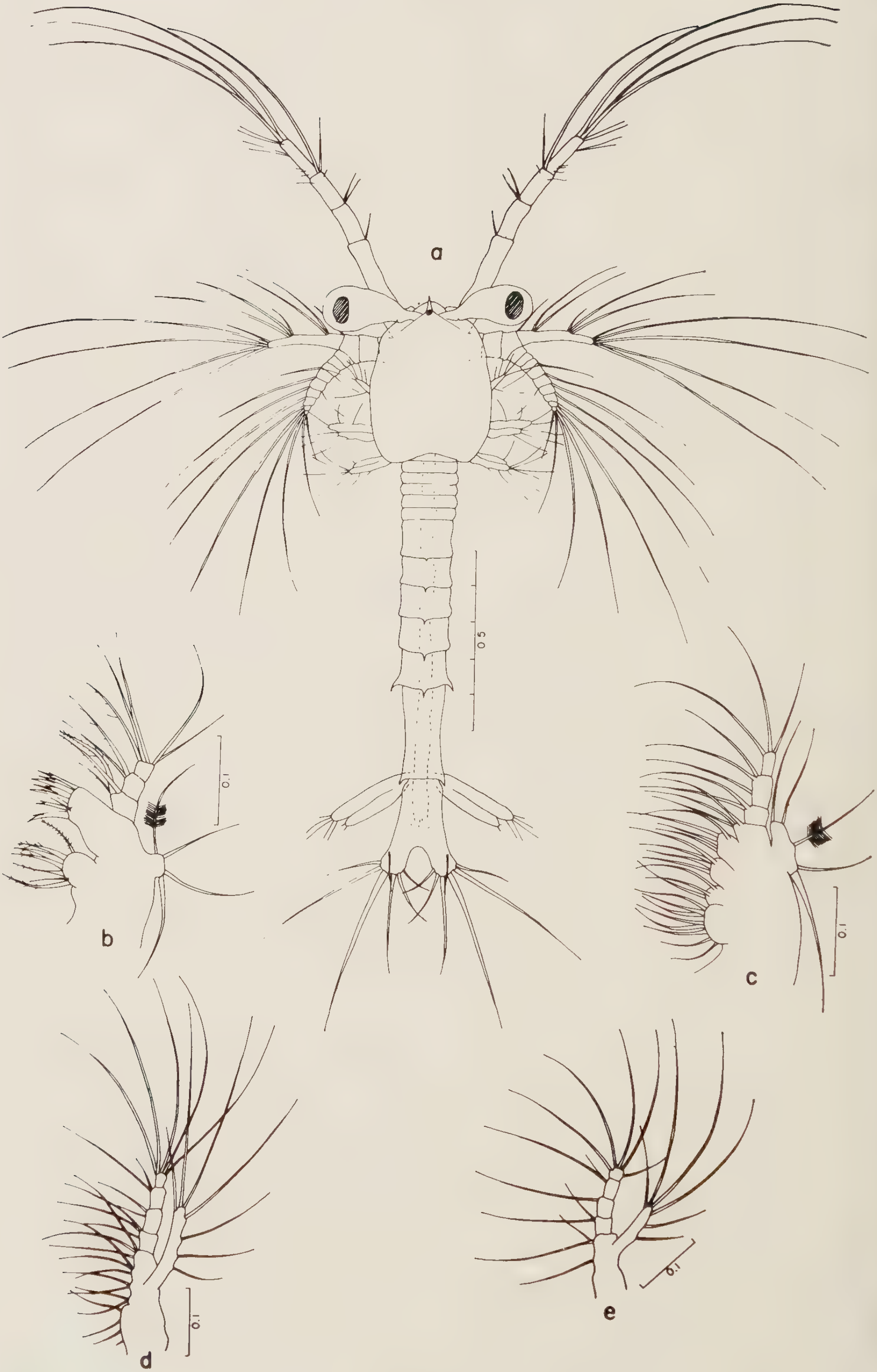

a
0.5
b
0.1
c
0.1
d
0.1
e
0.1

Figure 9. Protozoea III.

- a. Dorsal view
- b. Maxilla I
- c. Maxilla II
- d. Maxilliped I
- e. Maxilliped II

the first maxilla in the preceding substage has been lost. Such condition might indicate a variable number of setae on this segment. A second seta is present on the second segment of the endopod of the first maxilliped. Although the pereiopods have developed further and are biramous, they are still nonfunctional.

Segmentation of the abdomen is more distinct in this substage. Each of the first five segments bears a median spine on its dorsoposterior border. The fifth segment also has a pair of posterolateral spines, as does the sixth.

The telson is now separated from the sixth segment and each lobe retains seven caudal spines. A pair of biramous uropods originate from the ventroanterior margin of the telson. The exopod is slightly longer than the endopod and five or six setae arise from its apex. The endopod usually has two very small terminal setae.

J. *Mysis I* (Fig. 10)
Mean TL = 2.47 mm (2.16-2.66 mm);
mean CL = 0.82 mm (0.74-0.89 mm);
N = 24

At the molt to the first mysis substage, the larva undergoes another fundamental modification in body form, taking on a semblance of the adult for the first time. The transfiguration is exemplified in the functional pereiopods with their long brushlike exopods, and by the transformation of the first and second antennae into the adult shape.

The carapace has a short rostrum that extends slightly less than half the length of the eye. A single spine is found on the dorsal carina of the carapace. Supraorbital and pterygostomian spines are present.

The ocellus and occular papillae persist in this and succeeding mysis substages.

The first antenna consists of three segments. The first segment, which is about twice the length of the second and third combined, bears two spines, one on its median margin, and one on its lateral margin. The distal segment gives rise to two branches; the lateral, bearing five or six setae, is three times as long as the median, which bears a single seta. A series of setae are present along the margins of the appendage, and numerous setae arise from the apex of each segment.

The second antenna is composed of a two-segmented protopod (the basal segment is not shown in fig. 10), an unsegmented endopod with two lateral and three terminal setae, and an unsegmented, flattened exopod which bears 10 setae along its median and apical margins as well as a single, subterminal, externolateral seta.

The mandible has undergone no appreciable change. A short spine, added at the base of the second lobe of the protopod of the first maxilla, is the only difference. The exopod of the second maxilla has enlarged and now bears nine setae. An additional seta is present at both the apex of the protopod and on the endopod of the first maxilliped. The first and second segments of the endopod of the second maxilliped have each gained two setae, and two lateral setae have been lost from the exopod.

The third maxilliped and five pereiopods have become enlarged and possess long unsegmented exopods which bear six to eight setae. The protopod of the third maxilliped is unsegmented and bears four setae. Its endopod is composed of four segments, the first giving rise to one seta; the second, none; the third, three; and the fourth, five. The protopod of the first pereiopod is two-segmented with only a single seta present on the second segment. The endopod of the first pereiopod has been modified to form a rudimentary chela bearing three setae. The other four pereiopods were not examined in detail.

A ventromedian spine arises from each of the first five abdominal segments; the pleura, however, normally do not bear spines. Infrequently, laboratory-reared mysis exhibited dorsoposterior spines on the fourth, fourth and fifth, or fifth segments. Since examination of *Sicyonia* mysis from the plankton has failed to yield a specimen with dorsoposterior spines, their presence is tentatively regarded as an abnormal condition. The sixth segment possesses a dorsomedian spine and a pair of posterolateral spines.

The uropod has developed an unsegmented protopod which bears a posteroventral and a posterolateral spine. The endopod and exopod are of equal length and bears numerous setae on their margins.

The telson, deeply cleft, bears six pairs of terminal and subterminal spines, and a single pair of lateral spines.

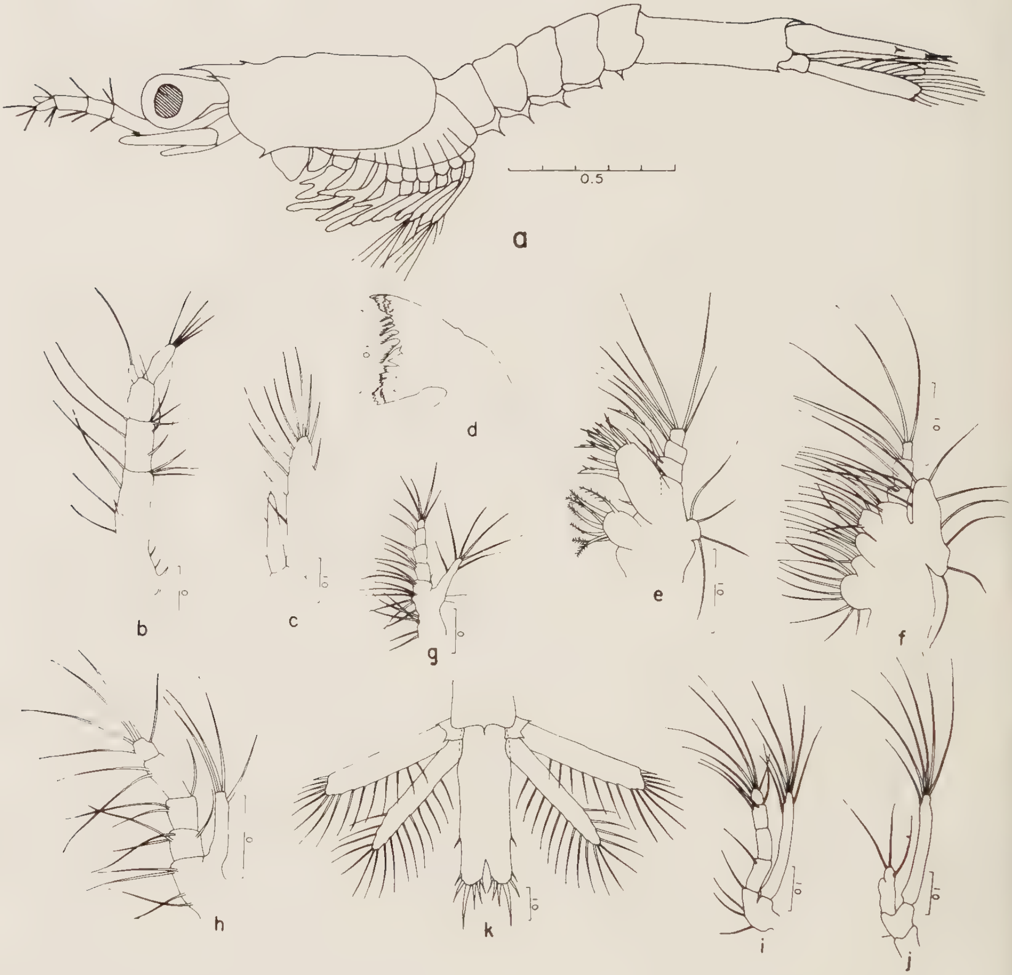


Figure 10. Mysis I.

**a.** Lateral view
**b.** Antenna I
**c.** Antenna II
**d.** Mandible
**e.** Maxilla II
**f.** Maxilla II
**g.** Maxilliped I
**h.** Maxilliped II
**i.** Maxilliped III
**j.** Periopod I
**k.** Telson

K. *Mysis II* (Fig. 11)
Mean TL = 2.89 mm (2.70-3.15 mm);
mean CL = 0.96 mm (0.90-1.05 mm);
N = 13

A second spine is added to the dorsal carina of the carapace and there is now a well-developed antennal spine.

The first antenna remains unchanged, except that the developing statocyst can now be seen at the base of the appendage. The exopod of the second antenna now possesses a subterminal spine on its lateral margin and the number of median and apical setae has increased to 13.

The mandible bears a large unsegmented palp. An exopod is no longer present on the first maxilla, and a seta has been lost from the second segment of the endopod. The endopod of the second maxilla has become further enlarged and the number of setae has increased to 24.

The protopods of the three maxillipeds are composed of two segments. The terminal seta added to the protopod of the first maxilliped in the last substage is no longer present. The first segment of the endopod has also lost a seta. The endopod of the second maxilliped has gained a terminal seta.

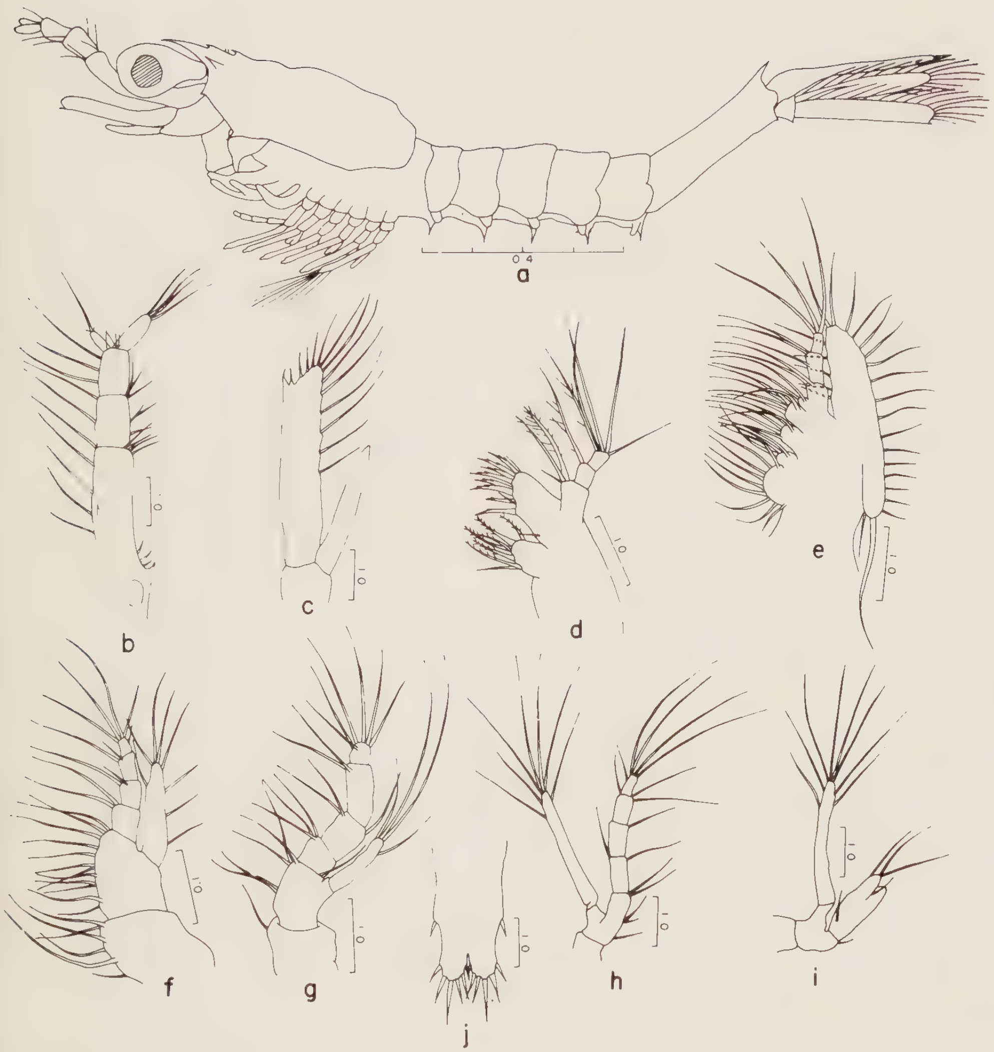


Figure 11. Mysis II

**a.** Lateral view
**b.** Antenna I
**c.** Antenna II
**d.** Maxilla I
**e.** Maxilla II
**f.** Maxilliped I
**g.** Maxilliped II
**h.** Maxilliped III
**i.** Pereiopod I
**j.** Telson

A single seta has been added to both the first and second segments of the endopod of the third maxilliped. The chela of the first pereiopod now bears six setae. Rudiments of the branchiae are present as small lobes on the maxillipeds and pereiopods.

The addition of small unsegmented pleopods and a reduction in the width of the cleft in the telson represent the only major changes in the posterior portion of the body.

### L. *Mysis III* (Fig. 12)

Mean TL = 3.51 mm (2.94-3.72 mm);
mean CL = 1.13 mm (0.90-1.26 mm);
N = 18

An additional spine added to the dorsal carina of the carapace raises the count to three.

The antenna have been modified slightly; the basal segment of the first antenna has gained a lateral spine apically, the endopod

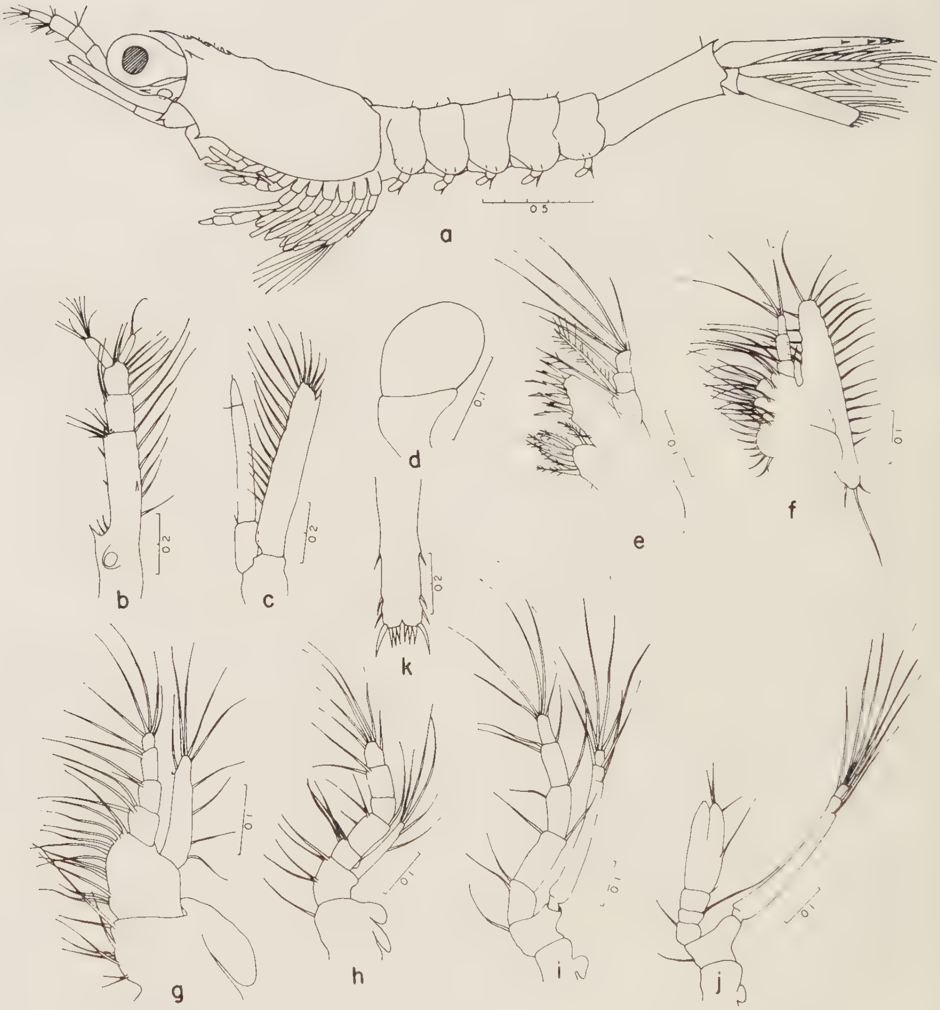


Figure 12. Mysis III.

**a.** Lateral view
**b.** Antenna I
**c.** Antenna II
**d.** Mandibular palp
**e.** Maxilla I
**f.** Maxilla II
**g.** Maxilliped I
**h.** Maxilliped II
**i.** Maxilliped III
**j.** Pereiopod I
**k.** Telson

of the second antenna is now made up of three segments and its exopod bears 19 setae.

The mandibular palp, composed of two segments, has enlarged further. The maxillae remain essentially unchanged from the preceding substage. Rudiments of the gills are present on the three maxillipeds and first pereiopod.

A seta has been added to both the first segment of the endopod and to the exopod of the first maxilliped. The endopod of the second maxilliped has gained an additional segment which does not bear setae. The distal segment of its protopod has lost two setae, leaving the protopod with one seta, while the exopod and the second segment of the endopod each have an additional seta. The endopod of the third maxilliped has gained a segment, making a total of five. The first three segments of the endopod now possess two setae each; the fourth segment, three; and the fifth, five. The exopod of the third maxilliped and of each pereiopod is now composed of two segments. The endopod of the first pereiopod is composed of four segments, with the distal segment being the rudimentary chela.

The posterior portion of the body has changed little. The pleopods, although now two-segmented, are still small. The cleft in the telson has become greatly reduced in size and the position of the spines has changed. There are now four pairs of terminal and three pairs of lateral spines. The postero-ventral spine on the protopod of the uropod is absent.

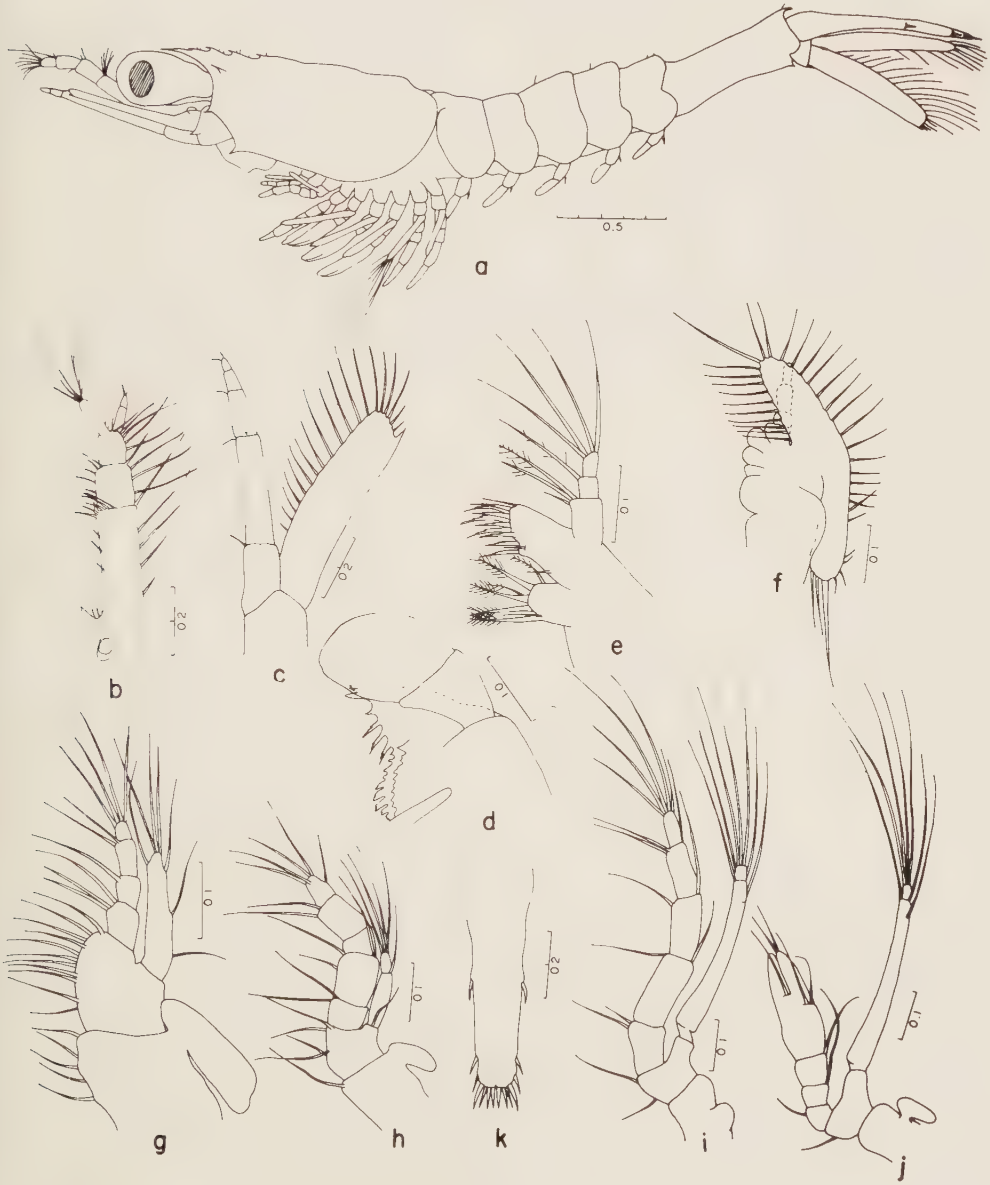


Figure 13. Mysis IV.
- **a.** Lateral view
- **b.** Antenna I
- **c.** Antenna II
- **d.** Mandible
- **e.** Maxilla I
- **f.** Maxilla II
- **g.** Maxilliped I
- **h.** Maxilliped II
- **i.** Maxilliped III
- **j.** Periopod I
- **k.** Telson

### M. *Mysis IV* (Fig. 13)

Mean TL = 3.68 mm (3.48-3.81 mm);
mean CL = 1.20 mm (1.11-1.23 mm);
N = 10

The fourth mysis differs only slightly from the preceding substage. The addition of a fourth rostral spine and a reduction in the cleft of the telson represent the most prominent modifications. The antennae have also undergone changes, with the endopod of the first antenna now composed of two segments, and that of the second, five segments.

The distal segment of the endopod of the first maxilla has lost a seta. The number of setae on the exopod of the second maxilla has increased to 36 and, although not shown in Fig. 13f, the setation of the protopod and exopod remains unchanged. The second and fourth segments of the endopod of the first maxilliped have each lost a seta, and the exopod, two. The number of setae on the protopod of the second maxilliped, and that of the second and fifth segments of its endopod, has increased and decreased by

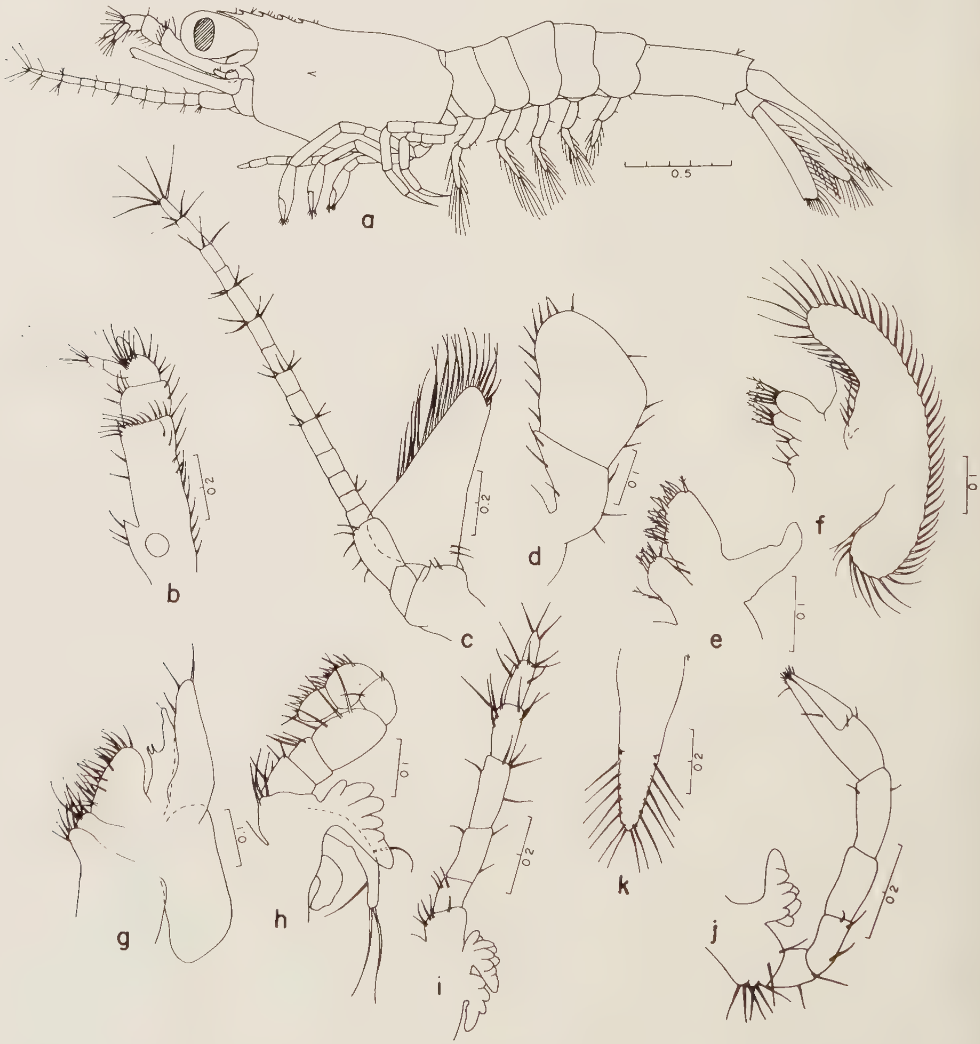


Figure 14. Postlarva I.

**a.** Lateral view
**b.** Antenna I
**c.** Antenna II
**d.** Mandibular palp
**e.** Maxilla I
**f.** Maxilla II
**g.** Maxilliped I
**h.** Maxilliped II
**i.** Maxilliped III
**j.** Pereiopod I
**k.** Telson

one, respectively; its exopod is now two-segmented.

The pleopods retain essentially the same shape, but have increased in length and are now about one and one-half times the length of those of the previous substage.

### N. *Postlarva I* (Fig. 14)

Mean TL = 3.87 mm (3.51-4.35 mm);
mean CL = 1.13 mm (1.07-1.21 mm);
N = 9

With the molt to postlarva, the exopods are lost from the pereiopods and the pleopods, now heavily setose, are the principal swimming organs.

The rostrum is short, extending about one-half the length of the eye. The carapace usually bears four teeth on its dorsal carina, although some specimens show a small fifth spine anteriorly. Hepatic and antennal spines are present, the supraorbital and pterygostomian spines having been lost.

The ocellus persists, but the ocular papillae are no longer present.

Although there is no appreciable change in the first antenna, the endopod (flagellum) of the second antenna is elongate and composed of 16 segments, while the exopod (antennal blade) is very broad at its base.

The mandibular palp has increased in size and bears about 20 setae along its margin. The endopod of the first maxilla is reduced greatly and is no longer setose. The endopod of the second maxilla is also vestigial, and the spines on the four lobes of the protopod are less prominent. The exopod has enlarged greatly and possesses about 60 setae.

Both the endopod and exopod of the first maxilliped are greatly reduced in size and setation. The second maxilliped retains a greatly reduced exopod, while the third maxilliped and the pereiopods have lost their exopods. The second maxilliped has become recurved and bears numerous spinelike setae on the last two segments. The dactyls of the chelipeds are fully formed. Although still rudimentary, the branchiae on the maxillipeds and pereiopods have developed two rows of small protuberances on their external surfaces.

The first five abdominal segments do not possess spines. The sixth segment has a small dorsomedian and a small pair of posterolateral spines.

The uniramous pleopods have lengthened and bear about 12 setae on the second segment.

The protopod of the uropod retains a small posterolateral spine. The endopod and exopod are of equal length.

The telson is no longer cleft, ending instead in a blunt point. It bears five pairs of minute lateral spines and seven pairs of setae.

## IV. CHRONOLOGY OF LARVAL DEVELOPMENT

Experiments by the authors with larvae of the brown shrimp, *Penaeus aztecus* Ives, showed that growth is closely related to temperature, becoming more rapid the warmer the water. Consequently, it is likely that the growth of *S. brevirostris* would also be accelerated at temperatures higher than those encountered during this rearing trial (21.0° to 24.6° C).

In this study, the eggs were spawned at night and hatched the following afternoon. Each nauplial substage lasted approximately 12 hours. The number of days after spawning when the indicated substages were first noted are listed in Table I.

TABLE 1
*Chronology of larval development*

| Substage | Days after spawning |
|---|---|
| Protozoea I | 3 |
| Protozoea II | 6 |
| Protozoea III | 10 |
| Mysis I | 12 |
| Mysis II | 16 |
| Mysist III | 22 |
| Mysis IV | 24 |
| Postlarva 1 | 29 |

## V. COMPARISON WITH DEVELOPMENT OF OTHER *Sicyonia*

As has been described, the larvae of *S. brevirostris* pass through five nauplial, three protozoeal, and four mysis substages before molting to the first postlarval stage. This sequence differs from that of the larval development of other (littoral) penaeidae in the northern Gulf area, most of which pass through only three mysis substages (Cook, in press), as well as from that of larvae of other *Sicyonia* spp. described in the literature (Table 2). One reason for the variation among descriptions by different authors may be that the number of substages is influenced by the environment in which the larvae grow. For example, Pike and Williamson (1964)

TABLE 2

*Major differences between corresponding substages of four species of Sicyonia larvae*[1]

| Stage and structure | *S. brevirostris* | *S. stimpsoni* | *S. wheeleri* | *S. carinata* |
|---|---|---|---|---|
| *Nauplius I* | | | | |
| Length (mm) | 0.30 (0.28-0.32) | 0.24-0.26 | See footnote 2 | Heldt attributes 8 nauplial substages to *S. carinata*. As illustrations of all substages are not given and setation is not described in detail, we have not attempted to compare this species with the other three. Length of the first nauplius is 0.26 mm and that of the last is 0.38 to 0.40 mm. |
| Antenna II | | | | |
| Endopod | 2 lateral and 2 terminal setae | No lateral and 2 terminal setae | | |
| Exopod | 5 setae | 4 setae | | |
| Caudal spines | 1 pair | 1 pair | | |
| *Nauplius II* | | | | |
| Length (mm) | 0.31 (0.29-0.34) | 0.26-0.30 | 0.28 | |
| Antenna II | | | | |
| Endopod | 2 lateral and 2 terminal setae | No lateral and 3 terminal setae | No lateral and 2 terminal setae | |
| Exopod | 6 setae | 5 setae | 6 setae | |
| Caudal spines | 1 pair | 1 or 2 pairs | 1 pair | |
| *Nauplius III* | | | | |
| Length (mm) | 0.35 (0.32-0.37) | 0.30-0.36 | 0.34-0.37 | |
| Antenna II | | | | |
| Endopod | 2 lateral and 3 terminal setae | No lateral and 4 terminal setae | No lateral and 3 terminal setae | |
| Exopod | 7 setae | 6 setae | 7 setae | |
| Caudal spines | 3 pairs | 2 or 3 pairs | 3 pairs | |
| *Nauplius IV* | | | | |
| Length (mm) | 0.37 (0.33-0.40) | 0.36-0.40 | See footnote 2 | |
| Antenna II | | No lateral and 4 terminal setae | | |
| Endopod | 2 lateral and 3 terminal setae | 7 setae | | |
| Exopod | 8 setae | 6 or 7 pairs | | |
| Caudal spines | 5 pairs | | | |
| *Nauplius V* | | | | |
| Length (mm) | 0.44 (0.38-0.46) | 0.36-0.42 | 0.4 | |
| Antenna I | 2 long terminal setae | 2 long terminal setae | 3 long terminal setae | |
| Antenna II | | | | |
| Endopod | 5 lateral and 4 terminal setae | 1 lateral and 3 terminal setae | 4 lateral and 4 terminal setae | |
| Exopod | 9 setae | 8 setae | 8 setae | |
| Caudal spines | 7 pairs | 7 pairs | 6 pairs | |
| *Protozoea I* | | | | |
| Length (mm) | 0.81 (0.70-0.99) | 0.70-0.80 | 0.7-0.75 | 0.76-0.86 |
| Antenna I | 5 terminal and 1 dorsolateral setae | 4 terminal and no dorsolateral setae | 5 terminal and 1 dorsolateral setae | 5 terminal and 1 dorsolateral setae |
| Antenna II | | | | |
| Endopod | 1 + 2 + 3 lateral setae[3] | 2 + 2 lateral setae | 1 + 2 lateral setae | 1 + 1 + 2 lateral setae |

| | | | | |
|---|---|---|---|---|
| Length (mm) | 1.23 (1.12-1.44) | 1.0 | 1.02 | 1.23-1.30 |
| Antenna I | 5 terminal and 2 dorsolateral setae | 5 terminal and no dorsolateral setae | 5 terminal and 1 dorsolateral setae | 5 terminal and 1 dorsolateral setae |
| Antenna II Endopod | 1 + 2 + 3 lateral setae | 2 + 2 lateral setae | 1 + 2 lateral setae | 1 + 2 + 2 lateral setae |
| *Protozoea III* | | | | |
| Length (mm) | 1.96 (1.84-2.09) | 1.36-1.68 | 1.32-1.5 | [not given] |
| Antenna II Endopod | 1 + 2 + 3 lateral setae | 2 + 2 lateral setae | 1 + 2 lateral setae | 1 + 2 + 2 lateral setae |
| Abdomen | First 5 segments with spine on dorsoposterior border, 1 pair of posterolateral spines present on both the fifth and sixth segments | Dorsoposterior spine present only on third, fourth, and fifth segments; no posterolateral spines on fifth or sixth segments | First 5 segments with spine on dorsoposterior border; 1 pair of posterolateral spines on fifth segment and 2 pairs on the sixth | First 5 segments with spine on dorsoposterior border; 1 pair of posterolateral spines on fifth segment and none on the sixth |
| *Mysis I* | | | | |
| Length (mm) | 2.47 (2.16-2.66) | See footnote 4 | 1.66 | 2.05-2.39 |
| Abdomen | Ventral margins of pleura of first 5 segments rounded; a pair of posterolateral spines on sixth segment | | Ventral margins of pleura of first 4 segments pointed | Ventral margins of pleura of first 5 segments rounded; no posterolateral spines on sixth segment |
| *Mysis II* | | | | |
| Length (mm) | 2.89 (2.70-3.15) | 2.0-2.8 | 1.8 | 2.6-2.8 |
| Abdomen | Same as in Mysis I | Ventral margins of pleura of first 5 segments pointed | Ventral margins of pleura of first 3 segments pointed | Same as in Mysis I |
| *Mysis III* | | | | |
| Length (mm) | 3.51 (2.94-3.72) | 2.8-3.6 | 2.37 | 2.95-3.04 |
| Abdomen | Same as in Mysis I | Ventral margins of pleura of first 5 abdominal segments pointed; point arises from the middle of the segment on all segments | Ventral margins of pleura of first 5 segments pointed; point arises from the posterior portions on segments 3-5 | Same as in Mysis I |
| *Mysis IV* | | | | |
| Length (mm) | 3.68 (3.48-3.81) | None recorded | None recorded | 3.26 |
| Abdomen | Same as in Mysis I | | | Same as in Mysis I |

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[1] Data on *S. stimpsoni* from Pearson (1939), on *S. wheeleri* from Gurney (1943), and on *S. carinata* from Heldt (1938).

[2] Gurney (1943) lists only three nauplial substages but concedes that he may have missed some. We have arbitrarily placed his nauplii into the second, third, and fifth substages as they appear similar to corresponding substages of both *S. brevirostris* and *S. stimpsoni.*

[3] The number of setae at each point of insertion is recorded starting proximally.

[4] Pearson (1939) recorded only two mysis substages, which we believe correspond to Myses II and III of the other species.

found that under certain conditions, larvae of *Pandalus montagui* Leach reared in the laboratory passed through several additional zoeal substages before molting to megalopa. To ensure that the number of substages listed for *S. brevirostris* in this paper is the same as occurs in nature, and was not affected by the rearing procedure, a comparison was made with *Sicyonia* larvae in plankton samples. The number of substages found in a large volume of planktonic material was the same as that found among laboratory-reared larvae.

Larvae of three other species of *Sicyonia* have been described: *S. carinata* by Heldt (1938); *S. stimpsoni* by Pearson (1939); and *S. wheeleri* by Gurney (1943). Upon comparing descriptions of these larvae with specimens of *S. brevirostris,* we determined that in the protozoeal and mysis stages they possess morphological characters which permit their differentiation both from other penaeid larvae and from each other. Variation between nauplii of different *Sicyonia* often appears to be as great as that observed between penaeid genera at the nauplial stage, and there seemingly are no definitive characters by which they can be collectively separated from nauplii of other genera. This is due to the fact that penaeid nauplii are very simple forms having the same general shape and relatively few setae, all of which minimizes the possibility of distinctive, interspecific variation.

The following characters serve to distinguish *Sicyonia* protozoeae from those of other penaeid genera: The first antenna is relatively long, about 1½ times as long as the endopod of the second antenna, and bears three long terminal setae. The rostrum, when present, is very short with no supraorbital spines. The labrum does not possess a ventral spine, and the outer pair of caudal spines extends inwardly across the furcae.

The lack of dorsomedial spines on the first five abdominal segments is usually a sufficient criterion for identifying *Sicyonia* myses. Other useful characters are the presence of ventromedial spines on the first five abdominal segments, and the absence of hepatic spines on the carapace.

As pointed out by Heldt (1938), metamorphosis among the Penaeidae is very gradual with relatively minor differences separating most substages. Because distinction of successive substages can only be accomplished somewhat arbitrarily, different investigators examining the same kind of developmental material might easily have different opinions as to the number of substages represented. We believe this subjectively largely explains the variation in substage count recorded for *Sicylonia* larvae (Table 2). So, to facilitate comparison of the species described in Table 2, we have taken the liberty of placing the larvae of some authors in slightly different substage categories.

## VI. SUMMARY

Five nauplial, three protozoeal, four mysis, and the first postlarval stages of the rock shrimp, *Sicyonia brevirostris* Stimpson, reared from eggs spawned in the laboratory, are described and illustrated. Temperatures during rearing varied between 21.0° and 24.6° C. Salinity, which was 24.5‰ at the start, rose to a maximum of 27.4‰. The pH varied from 8.06 to 8.20. Under these conditions, the larvae developed to the first postlarval stage in 29 days.

*S. brevirostris* larvae are compared with corresponding substages of three previously described species of *Sicyonia.* It was noted that the larvae of all four species possess characteristics which serve to distinguish them from one another.

## VII. LITERATURE CITED

ANDERSON, W. W., and M. J. LINDNER, 1943. A provisional key to the shrimps of the Family Penaeidae with especial reference to American forms. *Trans. Amer. Fish. Soc.*, 73: 284-319.

COOK, H. L., in press. A generic key to the protozoean, mysis, and postlarval stages of the littoral Penaeidae of the northwestern Gulf of Mexico. *Fish. Bull. U. S. Fish. Wildlife Serv.*

GURNEY, ROBERT, 1943. The larval development of two Penaeid prawns from Bermuda of the genera *Sicyonia* and *Penaeopsis. Proc. Zool. Soc. Lond., Ser. B.*, 113: 1-16.

HELDT, JEANNE H., 1938. La reproduction chez les Crustacés Décapodes de la famille des Pénéides. *Ann. Inst. Océanogr. Monaco*, 18: 31-206.

LUNZ, G. ROBERT, 1945. Carolina shrimps of the genus *Eusicyonia.* The *Charleston Museum Leaflet No.* 20, 12 p., Charleston, S. C.

————, 1957. Notes on rock shrimp *Sicyonia brevirostris* (Stimpson) from exploratory trawling off the South Carolina coast. *Contributions from Bears*

*Bluff Laboratories, No.* 25, 10 p., Wadmalaw Island, S. C.

PEARSON, JOHN C., 1939. The early life histories of some American Penaeidae, chiefly the commercial shrimp, *Penaeus setiferus* (Linn.). *Bull. U. S. Bureau Fish.*, 49(30): 1-73.

PIKE, R. B., and D. S. WILLIAMSON, 1964. The larvae of some species of Pandalidae (Decapoda). *Crustaceana*, 6: 265-284.

October 11, 1965

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# An Unusually Large Menhaden, *Brevoortia tyrannus* (Latrobe), from Rhode Island

A specimen of the menhaden, *Brevoortia tyrannus* (Latrobe), was taken by the author, with SCUBA, from the netting of a fish trap one-quarter mile south of Newport, Rhode Island (41°26' N, 71°15' W) on 7 July 1961. The total length of the fish (Figure 1) was 470 mm; standard length, 380 mm; fork length, 418 mm; body depth, 136 mm; and weight, 1,674 grams. Fin ray counts were: dorsal, 20; anal, 21; pectoral, 17; and pelvic, 7. Age determination by scales indicated that the fish was in its eighth year of life (courtesy of John W. Reintjes, BCF Biological Laboratory, Beaufort, N. C.).

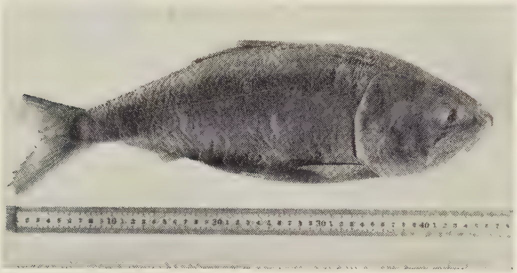

Figure 1.—The largest authenticated specimen of the menhaden, *Brevoortia tyrannus*, measuring 470 mm in total length and weighing 1,674 grams.

Although there are numerous length records of large menhaden, only a few of these references include body weight. Hildebrand (1963) stated that the largest specimen in the U. S. National Museum was 430 mm long. He also wrote that a specimen 480 mm long had been reported taken off Woods Hole, Massachusetts and one of 500 mm, weighing 1,587 grams, off Beaufort, North Carolina. Bigelow and Schroeder (1953) stated that they had reports of a 457-mm specimen, and that the heaviest menhaden known to them on which they had information weighed 822 grams. The fish collected off Rhode Island appears to be the heaviest menhaden ever recorded, and is the longest specimen authenticated to date.

The specimen has been preserved in 20% formalin at the Biological Laboratory of the U. S. Bureau of Commercial Fisheries, Boothbay Harbor, Maine.

## LITERATURE CITED

Bigelow, Henry B., and William C. Schroeder. 1953. Fishes of the Gulf of Maine. U. S. Fish. Wildl. Serv., Fish. Bull. 74(53): 114.

Hildebrand, Samuel F. 1963. Family Clupeidae, *In* Fishes of Western North Atlantic. Sears Foundation for Marine Research, Memoir Number 1, Part 3, 630 p.

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## ABSTRACT

A tidal marsh ditch near Pensacola, Florida was treated with 0.2 pound of DDT per acre in March 1963, and observed for 4 months. Ninety-eight per cent of the animal mortality occurred within 3 weeks after treatment. A population of cyprinodont fish was restored by reproduction of surviving and introduced fish. DDT was detected in surface water samples 8 days after treatment but not after 14 days, while DDT was not detected in bottom water samples later than 1 day after treatment. Seven weeks after treatment, vegetation samples averaged 9.1 ppm of DDT, after reaching a maximum of 75 ppm of DDT 3 to 4 weeks after treatment. Sediment samples yielded more variable residues, averaging 0.76 ppm of DDT at 7 weeks after reaching a maximum of 3.35 ppm of DDT 6 weeks after treatment. Fish accumulated up to 90 ppm of DDT within 5 weeks after treatment. Highest DDT residues detected in fiddler crabs and snails ranged from 15 to 25 per cent of the average residues detected in fish. The net water movement as indicated by the distribution of Rhodamine B dye, the general distribution of DDT residues in all samples, and the difference in mortality of fish at two holding sites, indicated an accumulation of DDT in the lower marsh after treatment.

## INTRODUCTION

There is a need for more knowledge of the distribution, concentration, and elimination of pesticides in estuarine areas to determine pesticide levels toxic to the estuarine fauna, and to provide estimates of the potential hazard to man of pesticide residues in commercially important marine animals. The objectives of our study were to determine: (1) the effect of an application of 0.2 pound of DDT per acre on some animals of a typical marsh-ditch habitat; (2) the distribution and concentration of DDT in the system; and (3) the persistence of toxicity.

The study area lies 3.3 miles east of Pensacola Beach Casino on Santa Rosa Island, Florida. The island here is dune and marsh cut by ditches which usually empty into the adjacent sound. The marsh is a mixture of grasses and sedges. Larger plants include magnolia, sand pine, palmetto, and scrub live-oak occurring on spoil banks, or on natural higher ground. Windrows of vegetation on the adjacent Santa Rosa Sound beach have been treated in the past with 5 per cent DDT for control of sand flies. Prior to 1963, 3 per cent malathion or lindane was applied to the area for thermal-fog control of mosquitos. Control chemicals were not applied to the test ditch during this study.

The test ditch had a water surface area of 0.36 acre at mean water level and was 2,150 feet long. Capacity at high water, or heavy groundwater runoff was calculated to be 0.48 acre foot, and at low water 0.28 acre foot.

## METHODS

### *Effects on Animals*

Eight of the 12 fish species present in the marsh ditch (Table 1) were seined from the ditch and placed at holding sites C and D (Figure 1) during February and early March. Holding sites were approximately 45 × 9 feet, and were enclosed with ¼-inch mesh hardware cloth supported by stakes. The wire cloth was sunk 12 inches into the bottom, and oystershell was used for fill to prevent scouring.

Fiddler crabs (*Uca minax*) were placed in cages 24 × 24 × 6 inches made from hardware cloth. Two cages were suspended just below the water surface at holding sites C and D.

Technical grade DDT was applied at a rate of 0.2 pound of active ingredient per acre, a recommended rate for larval mosquito control. The formulation of DDT in 2 quarts of acetone was applied by small manual applicators to the entire ditch on 6 March 1963.

After treatment with DDT, mortality checks were made 1, 4, 24, 48, and 72 hours, and irregularly thereafter for a month. Dead animals from holding sites C and D, and throughout the ditch were retrieved with long-handled scoops, identified, and counted. The white sand bottom and shallow depth (13 to 17

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TABLE 1.—*Principal fish species from the tidal marsh ditch*

| Species | Common name | Total length (inches)[1] |
|---|---|---|
| *Adinia xenica* | Diamond killifish | 1.3 |
| [2]*Cyprinodon variegatus* | Sheepshead minnow | 0.5–2.5 |
| *Fundulus* sp. | – | 2.0 |
| [2]*Fundulus grandis* | Gulf killifish | 1.5–5.0 |
| [2]*Fundulus similis* | Longnose killifish | 1.3–3.5 |
| [2]*Lucania parva* | Rainwater killifish | 0.8–1.5 |
| [2]*Gambusia affinis* | Mosquitofish | 0.8–3.0 |
| [2]*Mollienesia latipinna* | Sailfin molly | 1.0–3.3 |
| *Leiostomus xanthurus* | Spot | 1.3–2.3 |
| *Gobionellus boleosoma* | Darter goby | 2.0 |
| [2]*Mugil cephalus* | Striped mullet | 1.0–7.0 |
| [2]*Menidia beryllina* | Tidewater silverside | 1.5–2.0 |

[1] Fish retained by ¼-inch mesh seine.
[2] Fish seined and used as test species at holding sites.

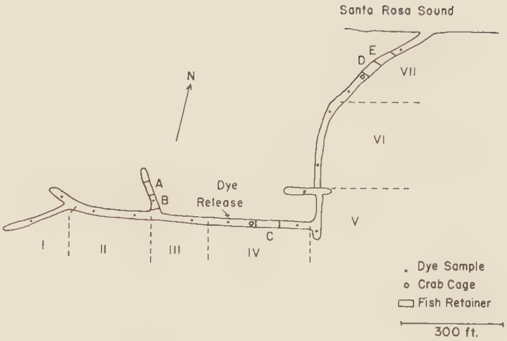

FIGURE 1.—Diagram showing tidal marsh ditch on Santa Rosa Island.

inches at sites C and D) made the retrieval of most animals possible.

An estimate of relative abundance of fishes outside holding sites was made before and after DDT treatment by making three hauls in each ditch area (Figure 1) with a ¼-inch mesh seine.

To check on the persistence of toxicity of DDT 1 month after treatment additional holding sites for fish were used (A, B, and E in Figure 1). Site D was reused after fish previously exposed were removed. Fish were then seined from other ditches on Santa Rosa Island and placed at holding sites A and D. Holding sites B and E were stocked with previously exposed fish taken from the test ditch. Species and numbers of fish at these sites are given in Table 2. Mortality checks were made daily for 1 month, and then weekly for 2 months.

Measurements of temperature and salinity were made at all holding sites during mortality checks. Salinity was determined by titration with silver nitrate.

## *Kinetics of DDT*

Samples of aquatic vegetation and sediment were taken weekly at holding sites and less frequently elsewhere. Samples of dead, dying, and living fish were taken periodically at holding sites and throughout the ditch. Although fish from the test ditch were not examined for DDT residues prior to treatment, fish were collected from other marsh ditches in the vicinity and were considered to be indicative of the history of the area. Two samples of living snails and all surviving fiddler crabs were also collected. All samples were placed in polyethylene bags and frozen. One liter water samples were collected at intervals and cooled until analysis to prevent bacterial breakdown of DDT residues. Bottom water samples were collected 4 inches from the bottom.

Rhodamine B (practical) was used to trace water movements and to provide an estimate of residence time of a pollutant in the ditch as described by Selleck and Pearson (1960). Dye was released in Area IV (Figure 1) before flood tide and allowed to disperse through the water for three tidal cycles. Duplicate water samples were then taken in each ditch area after 3 and 7 days during a half-hour period before flood tide.

Standard solutions of dye in marsh water were prepared in the laboratory, and fluorescent readings on a Turner Model 111 fluorometer were compared with samples of marsh water alone as a reagent blank. Primary and

TABLE 2.—*Species of introduced and exposed fish placed at holding sites A, B, D, and E one month after DDT treatment to check for persistence of toxicity*

| | Upper marsh | | Lower marsh | | |
|---|---|---|---|---|---|
| | Introduced (A)[1] | Exposed (B) | Introduced (D) | Exposed (E) | Total |
| Striped mullet | 82 | 65 | 71 | 71 | 289 |
| Sheepshead minnow | 74 | 24 | 65 | 45 | 208 |
| Rainwater killifish | 10 | | 6 | | 16 |
| Sailfin molly | 10 | | 12 | | 22 |
| Mosquitofish | 35 | 6 | 39 | 40 | 120 |
| Spot | 15 | | 15 | | 30 |
| Longnose killifish | 5 | | 2 | | 7 |
| Gulf killifish | 2 | | 3 | | 5 |
| Tidewater silverside | | | 9 | | 9 |
| Total | 233 | 270[2] | 222 | 156 | 881 |

[1] Site.
[2] Includes 175 fish of several species trapped at site B.

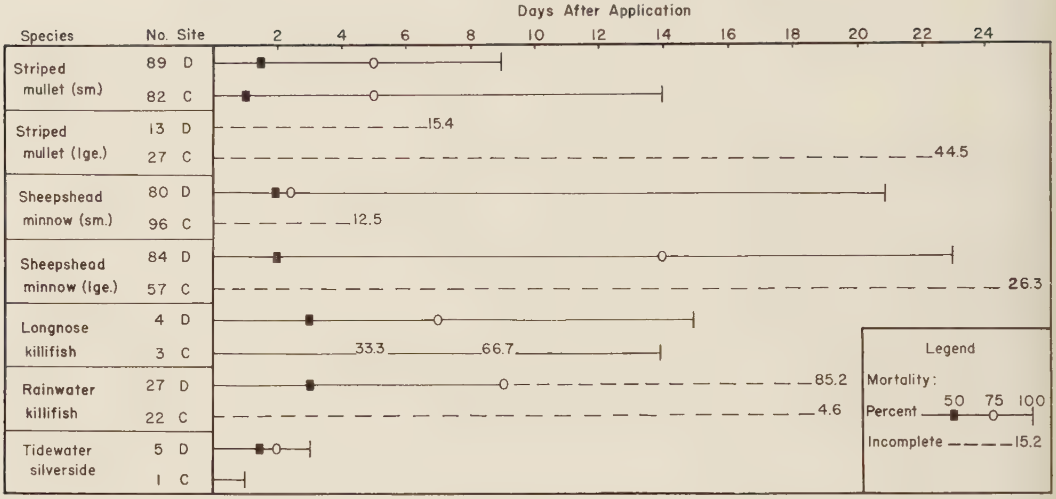

FIGURE 2.—Cumulative per cent mortality of fish held at holding sites C and D.

secondary filters were chosen to pass wavelengths greater than 570 m$\mu$ to rule out interference of naturally occurring fluorescent substances. Water samples from the field were brought to room temperature, and dye concentrations were determined for each ditch area. Physical adsorption and decay of dye in the field were considered to be low as indicated by exposure of standard dye solutions to suspended sediments, and light in the laboratory.

### *Analyses of DDT Residues*

A basic paper chromatography technique as reported by Mitchell (1958) and modified by Peterson (unpublished) was used to detect DDT residues in water, sediment, vegetation, and animal tissue samples. The method consists of four steps: drying, extraction, cleanup, and paper chromatography. Animal tissue was dried by grinding with anhydrous $Na_2SO_4$ in an electric blender, and extracted in a Soxhlet extractor with 10 per cent diethyl ether in petroleum ether. Vegetation and sediment samples were air dried and extracted with a 10 per cent ether mixture and acetone, respectively.[2] Water samples were extracted with petroleum ether in a separatory funnel.

To remove material that would interfere with the detection of DDT residues, the extracts were evaporated to dryness, dissolved in n-hexane, and extracted with acetonitrile. The n-hexane was then discarded and the acetonitrile evaporated to dryness. The fraction was again dissolved in n-hexane and extracted with 8 per cent fuming sulfuric acid. The acid was discarded and the n-hexane was passed through an anhydrous $Na_2SO_4$ column to remove acid traces. After evaporating the n-hexane to dryness, the residue was taken up in ethyl acetate to a known volume. With this procedure, the recovery of DDT from known samples ranged from 83 to 90 per cent.

## RESULTS

### *Animal Mortality*

Eighty-three per cent of the animal mortality outside holding sites occurred during the 3 days after treatment with DDT. Numbers of each species retrieved are given in Table 3. Small mullet were killed first, followed by eight cyprinodont fish species, silversides, spot, and gobies. A similar order of response was noted by Harrington and Bidlingmayer (1958) after an aerial application of dieldrin to a marsh at 1 pound per acre.

Cumulative per cent mortality of known numbers of fish at holding sites is given in Figure 2. Except for large mullet, 50 per cent

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[2] DDT residues reported in this paper are total ppm of DDT and its metabolites DDD and DDE on a wet weight basis for animal samples and a dry weight basis for vegetation and sediment samples.

TABLE 3.—*Mortality of animals outside holding sites during 1 month after treatment of a tidal marsh ditch with DDT at 0.2 pound per acre*

| Species | Number dead |
|---|---|
| Sheepshead minnow ¾ to 1.5 inches | 2,497 |
| Sheepshead minnow 1.5 to 2.5 inches | 1,323 |
| Striped mullet 1 to 2 inches | 617 |
| Striped mullet 4 to 7 inches | 25 |
| Longnose killifish | 91 |
| Rainwater killifish | 60 |
| Tidewater silverside | 25 |
| Sailfin molly | 12 |
| Gulf killifish | 8 |
| Diamond killifish | 8 |
| Spot | 7 |
| Mosquitofish | 5 |
| *Fundulus* sp. | 3 |
| Darter goby | 2 |
| Blue crab (*Callinectes sapidus*) | 12 |
| Fiddler crab (*Uca minax*) | 6 |
| Total dead | 4,701 |

TABLE 4.—*Relative abundance of fish in a marsh ditch before and after treatment with DDT at 0.2 pound per acre, and the subsequent reproduction of exposed and introduced fish*

| Type | Species | Observed mortality in March–April | Average number of fish[1] per 50-foot seine haul in February | June |
|---|---|---|---|---|
| Resident | Sheepshead minnow | 3,830 | 70 | 64 |
| | Rainwater killifish | 60 | 8 | 10 |
| | Sailfin molly | 12 | 5 | 22 |
| | Gulf killifish | 8 | 7 | 24 |
| | Mosquitofish | 5 | 6 | 11 |
| Transient | Striped mullet[3] | 617 | 23 | 13[2] |
| | Striped mullet[4] | 25 | 3 | 2 |
| | Longnose killifish | 91 | 4 | 1 |
| | Tidewater silverside | 25 | 4 | 0 |

[1] Total of three hauls with ¼-inch mesh seine in each ditch area.
[2] Average for hauls in Areas I and II only, not found elsewhere.
[3] Less than 2.0 inches.
[4] Longer than 4.0 inches.

of the fish held at site D died within 3 days after treatment with DDT. The mortality of fish at sites C and D was 37.7 and 91.3 per cent, respectively. The difference was significant at the 99 per cent level (0.0402 = S. E.). The difference in mortality between two groups of fiddler crabs placed at sites C and D (64 crabs at each site) was not significant at the 95 per cent level (0.1897 = S. E.).

Estimates of the relative abundance of fish outside holding sites before and after treatment with DDT are given in Table 4. Reproduction of all resident species beginning in March restored population levels by June. Approximately 80 per cent of the fish collected in June were juveniles. No silversides and few longnose killifish were collected in June, whereas spot were absent from all seine collections and were only collected dead during March.

No extensive attempt was made to estimate quantitatively the effect of treatment with DDT on the invertebrate fauna, however a population of shrimp (*Palaemonetes* sp.) was drastically reduced as shown by seine hauls in February and June, and dead shrimp were found in all ditch areas. Numerous annelid worms (primarily *Laonereis culveri*) were also found dead.

## *DDT Kinetics*

The net water movement in the ditch was towards salt water as indicated by the distribution of Rhodamine B dye. The dye was essentially removed from the ditch after 1 week when a trace was detectable only at the release site. Winds presumably modified this general water movement and influenced the distribution of DDT.

DDT was not detected in water samples taken from holding sites more than 5 days after treatment (Figure 3). Ninety per cent of all observed animal mortality occurred during this time. The highest concentration of DDT detected (0.133 ppm) was from the ditch outlet where an accumulation of oily DDT was

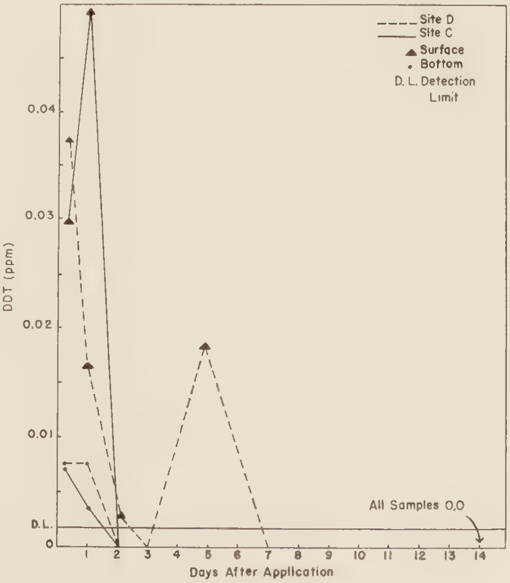

FIGURE 3.—Concentration of DDT residues detected in water samples from ditch sites.

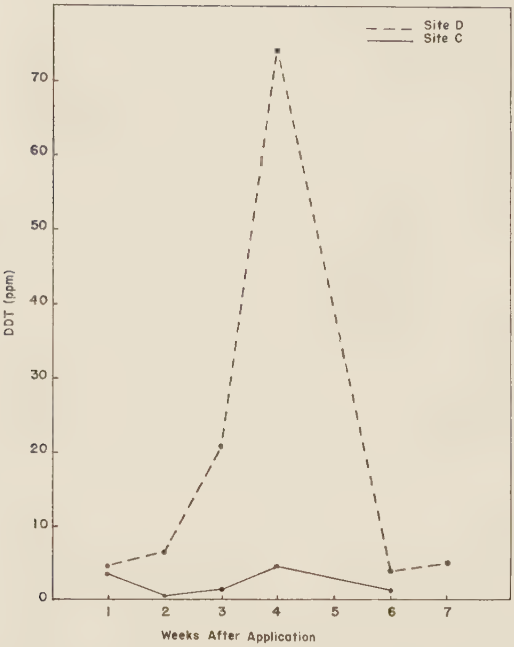

FIGURE 4.—Concentration of DDT residues detected in vegetation samples (*Ruppia maritima* and *Cladophora* sp.) from holding sites C and D.

seen on the water surface 8 days after treatment. None of the water samples collected 2 weeks after treatment yielded detectable DDT residues. Bottom water samples yielded low DDT residues and no detectable residues later than 1 day after treatment.

Vegetation and sediment samples from lower ditch areas generally yielded higher DDT residues than similar samples from the upper ditch (Figures 4 and 5). An exception was the detection of considerable DDT residues in sediment and vegetation samples from sites A and B where prevailing winds probably helped to accumulate residues in a ditch end (Table 5). The increase of DDT residues in vegetation samples, collected 2 to 4 weeks after treatment, accompanied the spring growth of aquatic plants and a drop in water level due to low rainfall and semi-isolation of the ditch from the adjacent sound. Seven weeks after treatment, vegetation samples averaged 9.1 ppm of DDT after reaching a maximum of 75 ppm of DDT 3 to 4 weeks after treatment, whereas sediment samples averaged 0.76 ppm of DDT at 7 weeks after reaching a maximum of 3.35 ppm of DDT 6 weeks after treatment.

The concentrations of DDT residues detected in exposed and unexposed fish are given in Tables 6 and 7, and those detected in exposed and unexposed fiddler crabs are given in Table 8. Two samples of 50 snails (*Neritina reclivata*) were collected from upper- and lower-ditch areas 6 weeks after treatment and yielded 2.52 ppm and 11.22 ppm of DDT residues, respectively. The highest DDT residues detected in fiddler crabs and snails ranged from 15 to 25 per cent of the average residues detected in fish.

The data indicate that fish and vegetation may accumulate up to 1,500 times the maximum amount of DDT residues detectable in the water, while for snails, crabs, and sediment, the accumulation values are 144, 99, and 66 respectively.

### *Persistence of Toxicity*

The mortality of exposed and introduced fish placed at holding sites A, B, D, and E a month after treatment and held for 3 months was low (4 per cent) and occurred within 3 to

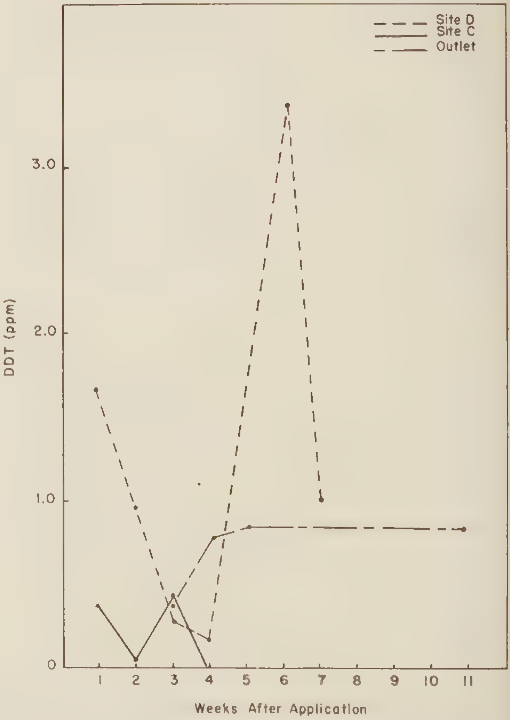

FIGURE 5.—Concentration of DDT residues detected in sediment samples from ditch sites.

10 days after placement. DDT residues were not detected in nine introduced fish found dead (spot, silversides, and mosquitofish). Twenty previously exposed sheepshead minnow and one gulf killifish were found dead and yielded 13.34 ppm and 89.15 ppm of DDT, respectively.

### *Salinity and Temperature*

During the 9 days after treatment with DDT the ditch maintained a small connection with the adjacent sound. Thereafter this connection was blocked, and low rainfall between 6 March and 3 April (0.13 inch) caused the water level in the ditch to drop during the month after treatment. The sand at the ditch outlet remained moist and some exchange of water is presumed. Water samples taken from around grass roots near the outlet yielded salinities ranging from 0.8 to 7.0‰ during March and early April. Salt water inflow occurred during 29 and 30 April, and late June. Several heavy rains occurred during June to maintain low salinities. The ranges of temperature and salinity for holding sites in the lower ditch were 11.3 to 33.0° C, and 0.1 to 26.8‰, respectively. For the upper ditch the ranges were 11.0 to 35.0° C, and 0.2 to 19.0‰.

## DISCUSSION

Butler (1963) reported an increasing resistance to acute toxicity of DDT in laboratory tests for juvenile mullet, longnose killifish, and juvenile blue crabs. The same order was found for the elapsed time before maximum mortality for these three species in the field (Figure 2).

Transient fish species (present at certain life history stages) made up 15 per cent of the total mortality of all fish retrieved. Two of these species, spot and striped mullet, are important commercial species whose young enter marsh areas during the spring and remain until they have grown to a length of about 3 inches (Townsen (unpublished); Anderson, 1958). Although young spot are reported to disperse into adjacent bays in June (Townsen (un-

TABLE 5.—*Concentration of DDT residues detected in sediment and vegetation samples from marsh ditch sites*

| Type | Location | Weeks after treatment | DDT (ppm) |
|---|---|---|---|
| Sediment | D | Pre-test | 0.30 |
| | C | Pre-test | ND[1] |
| | II | 4 | ND |
| | III | 4 | ND |
| | B | 6 | 0.03 |
| | B | 7 | 0.63 |
| | A | 6 | 0.01 |
| | A | 7 | 0.53 |
| | E | 6 | 0.36 |
| | E | 7 | 0.85 |
| | VII | 4 | 0.78 |
| Vegetation | I | 3 | 1.48 |
| | II | 4 | 4.03 |
| | III | 4 | 2.40 |
| | B | 6 | 1.21 |
| | B | 7 | 16.63 |
| | A | 6 | 1.57 |
| | A | 7 | ND |
| | E | 6 | 2.51 |
| | E | 7 | 13.91 |
| | VII | 4 | 6.47 |

[1] Not detectable.

TABLE 6.—*Concentration of DDT residues detected in exposed fish from the marsh ditch*

| Species | Number of fish | Location | Sample | Exposure (weeks) | DDT in whole fish ppm |
|---|---|---|---|---|---|
| Striped mullet[1] | 7 | I | Alive | 5 | 4.06 |
| Striped mullet[2] | 3 | III, IV | Alive | 2 | 14.70 |
| Striped mullet | 2 | C | Alive | 5 | 34.70 |
| Striped mullet | 2 | D | Alive | 5 | 57.60 |
| Striped mullet | 1 | D | Dead | 5 | 11.25 |
| Striped mullet | 2 | C | Dead | 3 | 24.96 |
| Sheepshead minnow | 6 | I, II | Dead | 3 | 17.15 |
| Sheepshead minnow | 10 | I | Alive | 5 | 2.44 |
| Sheepshead minnow | 11 | B | Dead | 5 | 13.34 |
| Sheepshead minnow | 18 | All | Dead | 3 | 18.59 |
| Sheepshead minnow | 7 | D | Dead | 2 | 23.95 |
| Sheepshead minnow | 14 | C | Alive | 5 | 22.27 |
| Rainwater killifish | 21 | C | Alive | 5 | 14.18 |
| Rainwater killifish | 11 | D | Alive | 5 | 22.70 |
| Sailfin molly | 9 | C | Alive | 5 | 44.27 |
| Sailfin molly | 3 | D | Alive | 5 | 33.36 |
| Gulf killifish | 3 | C | Alive | 5 | 33.94 |
| Gulf killifish | 1 | E | Dead | 5 | 89.15 |
| Mosquitofish | 15 | I | Alive | 5 | ND[3] |

[1] 1 to 2 inches.
[2] Longer than 4.0 inches.
[3] Not detectable.

TABLE 7.—*Concentration of DDT residues detected in live fish from various marsh ditch habitats on Santa Rosa Island*

| Species | Number of fish | DDT in whole fish (ppm) |
|---|---|---|
| Striped mullet[2] | 10 | 12.33 |
| Striped mullet | 40 | ND[1] |
| Striped mullet[3] | 3 | 39.24 |
| Sheepshead minnow | 40 | 0.33 |
| Sheepshead minnow | 15 | 0.42 |
| Sailfin molly and Rainwater killifish | 18 | 0.35 |
| Mosquitofish | 16 | ND |
| Mosquitofish | 9 | ND |
| Gulf killifish | 4 | 0.07 |
| Gulf killifish | 2 | 0.48 |
| Spot | 24 | ND |
| Spot | 30 | 0.67 |
| Tidewater silverside | 7 | 0.50 |

[1] Not detectable.
[2] 1 to 2 inches.
[3] Longer than 4.0 inches.

TABLE 8.—*Concentration of DDT residues detected in exposed and unexposed fiddler crabs* (Uca minax)

| Sample | Location | Number | DDT in whole crabs (ppm) |
|---|---|---|---|
| Unexposed | Gulf Breeze | 20 | 0.25 |
| | Santa Rosa Island | 20 | 0.27 |
| Exposed | D[1] | 4 | 3.16 |
| | D[2] | 20 | 4.97 |
| | C[1] | 8 | 1.38 |
| | C[2] | 25 | ND[3] |

[1] Exposed during the 2 weeks after DDT treatment.
[2] Exposed during the third and fourth weeks after DDT treatment.
[3] Not detectable.

published) ) young mullet 1½ to 3 inches long may remain in marsh areas during June and July in Georgia (Anderson, 1958) and in northwest Florida. The isolation of marsh areas from tidal flushing will further increase the residence time of both species.

Immigration of fish into the test ditch from the sound was considered negligible during the study period due to the barrier beach at the ditch mouth, a series of 0.25-inch mesh screens in the lower ditch, and no horizontal intrusion of salt water. Furthermore, there was an absence of young silversides from seine collections. Their presence usually indicates recent salt water inflow. For these reasons, the young of resident species present in June were considered to be offspring of exposed and introduced fish.

The interpretation of DDT residues in dead and surviving animals is difficult, but residues in surviving fiddler crabs from site D were higher than those in crabs from site C (Table 8). Considering the number of fish involved, and the time of exposure, the uptake of DDT appears greater by fish from the lower ditch (Table 6). Recent work has shown rapid uptake of $C^{14}$ labeled DDT from water by fish (Holden, 1962; Premdas and Anderson, 1963). This, in addition to behavioral differences, complicates the interpretation of DDT residues in fish.

The accumulation and localization of DDT residues on vegetation and sediment, and differential ingestion of this material by animals further complicates an analysis of animal tissue residues. Tidal marsh fishes are characterized by omnivorous diets, quick changes to alternative foods when certain items are scarce, and short food chains (Harrington and Harrington, 1961). Other marsh animals which feed on algae and organic detritus are fiddler crabs, annelid worms, and snails (Teal, 1962).

The residues of DDT detected in several species show little difference in amount of DDT whether from dead or live fish. A similar situation was reported for toxaphene residues detected in freshwater fish (Kallman et al., 1962). As they pointed out, the rate of uptake of chemical, and exact time of death of individual fish must be considered before deciding on the significance of a specific residue. The concentrations of DDT detected in "unexposed" fish (Table 7) were primarily those of the metabolites DDD and DDE, indicating past exposure to DDT. The degradation to these products proceeds at different rates in different individual fish (Cope, 1961).

Highly fluctuating concentrations of DDT residues were detected in sediment samples from most ditch areas, while sediments from the shallow outlet, containing much decomposing *Thalassia*, showed less variable DDT residues (Figure 5). Since DDT is essentially water insoluble, the accumulation of residues on the sediments is probably dependent on turbulence and water depth. Ditch sediments probably received part of their DDT residues from decomposing animal remains. Darnell (1961) and Odum and de la Cruz (1963) have stressed the importance of organic detritus as a major component in the estuarine ecosystem. Much of this detritus originates from decomposed grasses, e.g., *Spartina*, whose protein value is then increased (Teal, 1962). *Thalassia* produces a considerable portion of the detritus in Santa Rosa Island marsh areas. The bottom of the lower ditch was covered with a 3-inch thick layer of decomposing *Thalassia*, and fragments were present in sediment samples from other ditch areas. Little is known of the stability of DDT residues during the decomposition of this organic material to detritus.

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## LITERATURE CITED

ANDERSON, W. W. 1958. Larval development, growth and spawning of striped mullet (*Mugil cephalus*) along the south Atlantic coast of the United States. U. S. Fish and Wildl. Serv., Fish. Bull. 144: 501–519.

BUTLER, P. A. 1963. Commercial fisheries investigations. *In* Pesticide-wildlife studies: A review of Fish and Wildlife Service investigations during 1961–62. U. S. Fish and Wildl. Serv., Circ. 167: 11–25.

COPE, O. B. 1961. Effects of DDT spraying for spruce budworm on fish in the Yellowstone River system. Trans. Amer. Fish. Soc. 90(3): 239–251.

DARNELL, R. M. 1961. Trophic spectrum of an estuarine community based on studies of Lake Pontchartrain, Louisiana. Ecology 42(3) :553–568.

HARRINGTON, R. W., AND W. L. BIDLINGMAYER. 1958. Effects of dieldrin on fishes and invertebrates of a salt marsh. J. Wildl. Mgmt. 22(1): 76–82.

HARRINGTON, R. W., AND E. S. HARRINGTON. 1961. Food selection among fishes invading a high subtropical salt marsh: From onset of flooding through the progress of a mosquito brood. Ecology 42(4): 646–666.

HOLDEN, A. V. 1962. A study of the absorption of $C^{14}$ labeled DDT from water by fish. Ann. Appl. Biol. 50(3): 467–477.

KALLMAN, B. J., O. B. COPE, AND R. J. NAVARRE. 1962. Distribution and detoxication of toxaphene in Clayton Lake, New Mexico. Trans. Amer. Fish. Soc. 91(1): 14–22.

MITCHELL, L. C. 1958. Separation and identification of chlorinated organic pesticides by paper chromatography. XI. A study of 114 pesticide chemicals: technical grades produced in 1957 and reference standards. J. Assoc. Off. Agr. Chemists 41: 781–806.

ODUM, E. P., AND A. A. DE LA CRUZ. 1963. Detritus as a major component of ecosystems. Amer. Inst. Biol. Sci. Bull. 13(3): 39–40.

PREMDAS, F. H., AND J. M. ANDERSON. 1963. The uptake and detoxification of $C^{14}$ labeled DDT in Atlantic salmon, *Salmo salar*. J. Fish. Res. Bd. Canada 20(3): 827–837.

SELLECK, R. E., AND E. A. PEARSON. 1960. Tracer studies and pollutional analyses of estuaries. California Water Pollution Control Bd., Publ. 23: 1–139.

TEAL, J. M. 1962. Energy flow in the salt marsh ecosystem of Georgia. Ecology 43(4): 614–624.

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# Detection and Measurement of Organic Lampricide Residues

eat Lakes Fishery Commission

HNICAL REPORT No. 9

The Great Lakes Fishery Commission was established by the Convention on Great Lakes Fisheries, between Canada and the United States, ratified on October 11, 1955. It was organized in April, 1956 and assumed its duties as set forth in the Convention on July 1, 1956. The Commission has two major responsibilities: the first, to develop co-ordinated programs of research in the Great Lakes and, on the basis of the findings, recommend measures which will permit the maximum sustained productivity of stocks of fish of common concern; the second, to formulate and implement a program to eradicate or minimize sea lamprey populations in the Great Lakes. The Commission is also required to publish or authorize the publication of scientific or other information obtained in the performance of its duties.

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# DETECTION AND MEASUREMENT OF ORGANIC LAMPRICIDE RESIDUES

by

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# DETECTION AND MEASUREMENT OF ORGANIC LAMPRICIDE RESIDUES

Stacy L. Daniels, Lloyd L. Kempe, Thomas J. Billy
and Alfred M. Beeton

## ABSTRACT

The selective lampricide, 3-trifluoromethyl-4-nitrophenol (TFM), and its synergist, 5,2'-dichloro-4'-nitrosalicylanilide (DCN), are separable from natural waters by anion exchange. The adsorbed compounds can then be recovered from the resin as concentrates by elution with selective solvent mixtures. Measurements of the amounts of lampricides in the final concentrates can be made colorimetrically at 395 m$\mu$ for TFM and at 530 m$\mu$ for the safranin complex of DCN. TFM has also been separated for quantitative determination from homogenates of whole fish. The fish is first macerated in a blender and then hydrolyzed in hot, 3 N hydrochloric acid. The amount of background color, due to certain components of the fish in the hydrolysate, is reduced by one or a combination of three methods: (1) a series of three extractions with ether, methylene chloride, and benzene; (2) cation exchange followed by methylene chloride extraction; or (3) ether extraction followed by anion exchange and subsequent desorption with amyl acetate-acetic acid.

## Introduction

Interest has been growing in the distribution and concentration of pesticides and organic nutrients that may be part of the microorganic content of natural waters, bottom sediments, and animal tissues. The Bureau of Commercial Fisheries Biological Laboratory in Ann Arbor, has undertaken a study of these organic compounds in waters of the Great Lakes region in connection with work on control of the sea lamprey for the Great Lakes Fishery Commission. The detection and measurement of the selective lampricide, 3-trifluoromethyl-4-nitrophenol (TFM), and a synergistic compound, 5,2'-dichloro-4'-nitrosalicylanilide (DCN—also termed Bayluscide by Strufe, 1962, and Howell, *et al.*, 1964), have been of particular concern. Ordinary methods of chemical analysis must be preceded by concentration because of the extremely low levels of these lampricides to be expected as residues in the environment and/or fish.

The development of suitable analytical procedures for the separation, concentration, and detection of these lampricides has included a study of three techniques: adsorption onto activated carbon, adsorption onto ion-exchange resins, and solvent extraction. Activated-carbon adsorption was considered in an earlier paper (Daniels, et al., 1963); the procedure was a modification of a technique developed by the U. S. Public Health Service (Middleton, Rosen, and Burttschell, 1959). Ion-exchange and solvent extraction for the detection of lampricides in natural waters, bottom sediments, and fish tissues are described in the present paper.

The sodium salt of pure 3-trifluoromethyl-4-nitrophenol (TFM, mol. wt. 207.13) is a yellow-orange, crystalline solid that is soluble in water to the extent of approximately 5,000 ppm at 25° C. The free phenol has a melting point of 75° C. The 2-ethanolamine salt of 5,2'-dichloro-4'-nitrosalicylanilide (DCN, mol. wt. 370.2) is also yellow but is only sparingly soluble in water (230 ± 50 ppm at 25° C). The free compound melts at 216° C. Aqueous alkaline solutions of both compounds are intensely yellow; acidic solutions of TFM are colorless and those of DCN are faintly yellow.

Colorimetric methods have been developed for determining the quantity of TFM present in natural waters which possess conflicting background colors (Smith, Applegate, and Johnson, 1960; Ebel, 1962). DCN can be determined by direct colorimetric measurement of the potassium salt at 385 m$\mu$ or indirectly by complexing it with safranin dye, extracting into amyl acetate under basic conditions, and then measuring the color of the complex at 530 m$\mu$ (Strufe, 1962). The latter technique may be applicable for determining DCN in the presence of TFM since the latter compound has an absorption maximum at 395 m$\mu$ and does not form a complex with the safranin dye.

These colorimetric measurements, however, are limited to solutions containing about 0.1 ppm or greater. The lower limit for applicability of the test may be higher than 0.1 ppm if natural color and turbidity of water are significant. Measurements in samples containing lower levels of the lampricides are impossible without preliminary concentration of the dissolved components to detectable levels. Unfortunately, compounds other than the lampricides also may be concentrated to such a degree that the resulting background color obscures the determination (Shapiro, 1957, 1958). Some methods then must be employed to separate selectively and concentrate the lampricides.

## Ion Exchange of TFM and DCN in Water

The low capacity and poor selectivity of activated carbon for the concentration of the lampricides prompted substitution of synthetic ion-exchange resins for this work. The equilibrium between aromatic acids and weak-base exchangers has been studied (Peterson and Gowen, 1953). Sorption of phenols by anion-exchange resins has been reported (Chasanov, Kunin, and McGarvey, 1956) and p-nitrophenol has been observed to exchange (Anderson and Hansen, 1955). The ethanolamine salt of DCN can be exchanged on a cationic resin (Strufe, 1961). Phenolic compounds form negatively charged phenolate ions in basic solution and therefore should exhibit anion exchange. The potassium salts of both TFM and DCN exhibit strong affinities for Dowex[1] 1 × 8, a quaternary ammonium anion-exchange resin in the hydroxide form. Mixtures of TFM and DCN have also been exchanged, and it appears that separation may be achieved by selective elution. The DCN-safranin complex also exchanges under basic conditions. The presence of buffer salts does not appear to reduce the effectiveness of any of the exchanges.

Recovery of TFM from concentrated solutions containing approximately 1,000 ppm of the technical grade TFM (approx. 70 percent 3-trifluoromethyl-4-nitrophenol on a dry basis) in distilled water by the use of anion-exchange resins, followed by elution with selective solvent mixtures, indicated the presence of a number of colored impurities. These other colored components, such as isomers of TFM, dinitro compounds, . . . , are probably structurally related to 3-trifluoromethyl-4-nitrophenol. The manufacturer has reported the composition of crystalline technical grade TFM to be approximately 70 percent 3-trifluoromethyl-4-nitrophenol and 20 percent other isomers, principally 3-trifluoromethyl-6-nitrophenol. This is not surprising since these two isomers are present as the primary nitration products of meta-phenol (Noller, 1958). The general applicability of anion exchange for concentrating TFM would therefore be improved by a better knowledge of the nature and quantities of these impurities.

All of the isomers of TFM have similar spectra in the visible region (Table 1). These spectra are comparable to those of the parent nitrophenols. The position of the nitro group appears to dictate the wavelength at which maximum absorption occurs and the intensity of the color developed by a particular compound (Fig. 1). Other ring substitutions appear to have lesser influence on these characteristics. The type of solvent in which the spectra

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[1] Trade names referred to in this publication do not imply endorsement of commercial products.

Table 1.—Absorption maxima ($\lambda$ max) and molar absorptivities ($\epsilon$) for selected lampricides and related compounds

[All solutions are aqueous unless otherwise specified; values in parentheses are estimates]

| Compound | Form | Absorption maxima ($\lambda$ max) | Molar absorptivities ($\epsilon \times 10^{-4}$) |
|---|---|---|---|
| 2-nitrophenol[1] | Ortha isomer | 415 | 0.528 |
| 3-nitrophenol[1] | Meta isomer | 393 | 0.151 |
| 4-nitrophenol[1] | Para isomer | 399 | 1.95 |
| 3-trifluoromethyl-2-nitrophenol[2] | . . . | 405 | 0.234 |
| 3-trifluoromethyl-4-nitrophenol[2] | Recrystallized | 395 | 1.313 |
| 3-trifluoromethyl-4-nitrophenol[3] | 70 percent | 395 | 1.23 |
| 3-trifluoromethyl-4-nitrophenol[3] | 98 percent | 395 | 1.34 |
| 3-trifluoromethyl-5-nitrophenol[4] | . . . | (393) | (0.151) |
| 3-trifluoromethyl-6-nitrophenol[5] | . . . | (408) | (0.522) |
| 2-trifluoromethyl-4-nitrophenol[5] | . . . | (402) | (1.7) |
| 5,2'-dichloro-4'-nitrosalicylanilide[3] | 85 percent | 335<br>375 | 1.0<br>1.16 |
| 5,2'-dichloro-4'-nitrosalicylanilide[6] | Purified? | 330<br>380 | 1.1<br>1.6 |
| 5,2'-dichloro-4'-nitrosalicylanilide[7] | | 385 | . . . |
| 5,2'-dichloro-4'-nitrosalicylanilide[8] | Safranin O complex | 340<br>530 | . . .<br>. . . |
| 5,2'-dichloro-4'-nitrosalicylanilide[9] | Safranin TH complex | 530 | . . . |
| 2,7-diamino-3,6-dimethyl-10-phenyl phenazine[10] | Safranin O, 97 percent | 520 | 3.26 |

[1] 0.01 N NaOH (Lang, 1962).

[2] 1 percent NaOH (Smith, Applegate and Johnson, 1961).

[3] 0.01 N KOH

[4] Estimated from data for m-nitrophenol (Lang, 1962).

[5] Estimated from data for the corresponding halo-nitrophenols (Smith, Applegate and Johnson, 1961).

[6] Methanol (Schraufstatler, 1962).

[7] 0.01 N NaOH (Strufe, 1962).

[8] pH 9.0-9.5 KCl-KOH buffer extracted into amyl acetate.

[9] pH 9.0-9.5 KCl-KOH buffer extracted into amyl acetate (Strufe, 1962).

[10] pH 9.0-9.5 KCl-KOH buffer.

are determined is also important (Briegleb and Angerer, 1952; Lang, 1962).

The spectra of p-nitrophenol, 3-trifluoromethyl-4-nitrophenol (98 percent), and technical grade TFM (70 percent) can be compared (Fig. 2). The absorption maxima of all three are between 395 and 400 m$\mu$. The magnitudes of the molar absorptivities vary somewhat; p-nitrophenol is the highest, followed by 98-percent and 70-percent 3-trifluoromethyl-4-nitrophenol, respectively. The low absorptivity of technical grade TFM (based on a

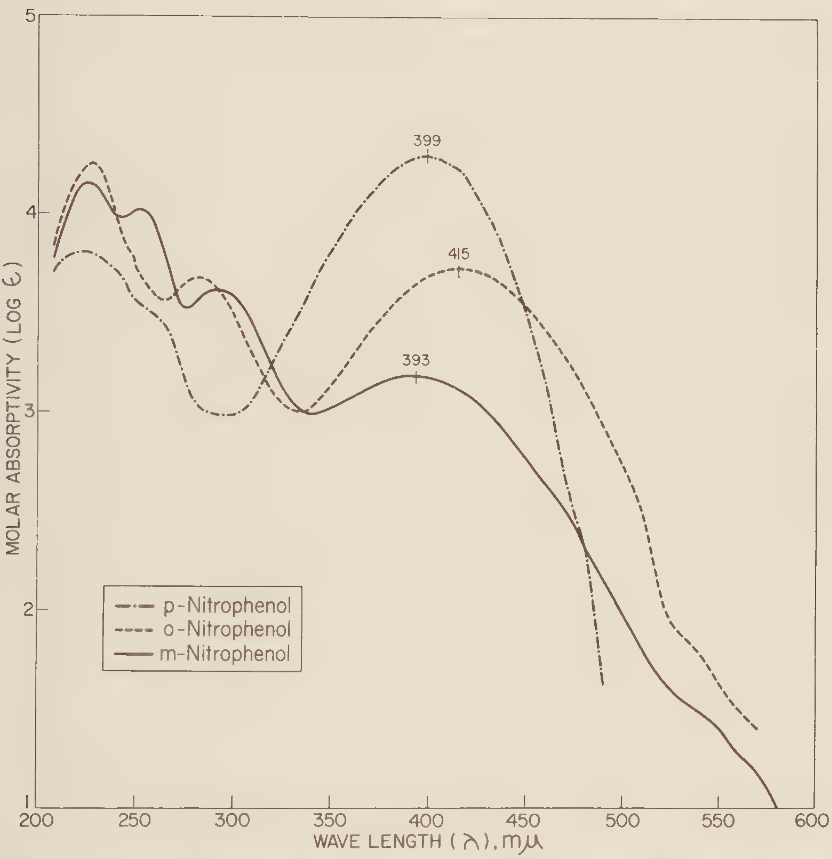


Figure 1.—Visible absorption spectra for selected nitrophenols (data from Lang, 1962).

molecular weight of 207.13) probably is due to a small fraction of impurities, principally the ortho-nitro isomers of 3-trifluoromethyl phenol, i.e., 2-nitro- and 6-nitro-3-trifluoromethyl phenol, which have relatively low maxima compared to the para isomer. The maximum absorption of 3-trifluoromethyl-4-nitrophenol (98 percent) is lower than that of p-nitrophenol due to the additional substitution of the trifluoromethyl group on the aromatic ring.

The absorption spectrum of the synergist, DCN (based on a molecular weight of 382.2 for the potassium salt), is similar to TFM in the visible range, but has a much broader maximum near 375 mμ and a secondary peak at 335 mμ (Fig. 3). Distinction between TFM and DCN cannot be made on the basis of visible-absorption measurements in aqueous solutions containing both compounds because of the overlapping absorption peaks. The

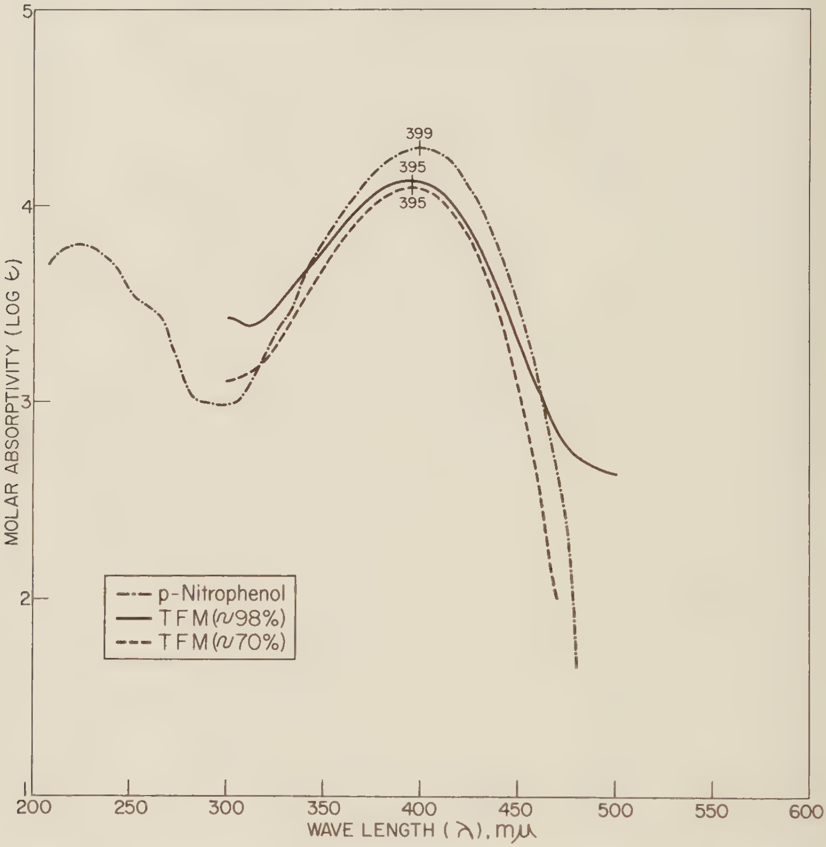


Figure 2.—Visible absorption spectrum of 3-trifluoromethyl-4-nitrophenol.

DCN-safranin dye complex exhibits a different spectrum possessing maxima at 335 and 530 mμ in amyl acetate solution. The complete visible spectrum of the DCN-safranin complex is not presented because of present uncertainty in the molar ratio. Because TFM does not complex with safranin it may be possible to determine DCN in the presence of TFM by using selective complexation and extraction into amyl acetate. Safranin and DCN separately are not appreciably soluble in amyl acetate.

A typical column, initially loaded with the technical TFM formulation, developed several distinctive bands of color upon elution with a solution of potassium hydroxide. The first two bands eluted from the column have been identified tentatively as the ortho-nitro isomers of 3-trifluoromethyl phenol, i.e., the

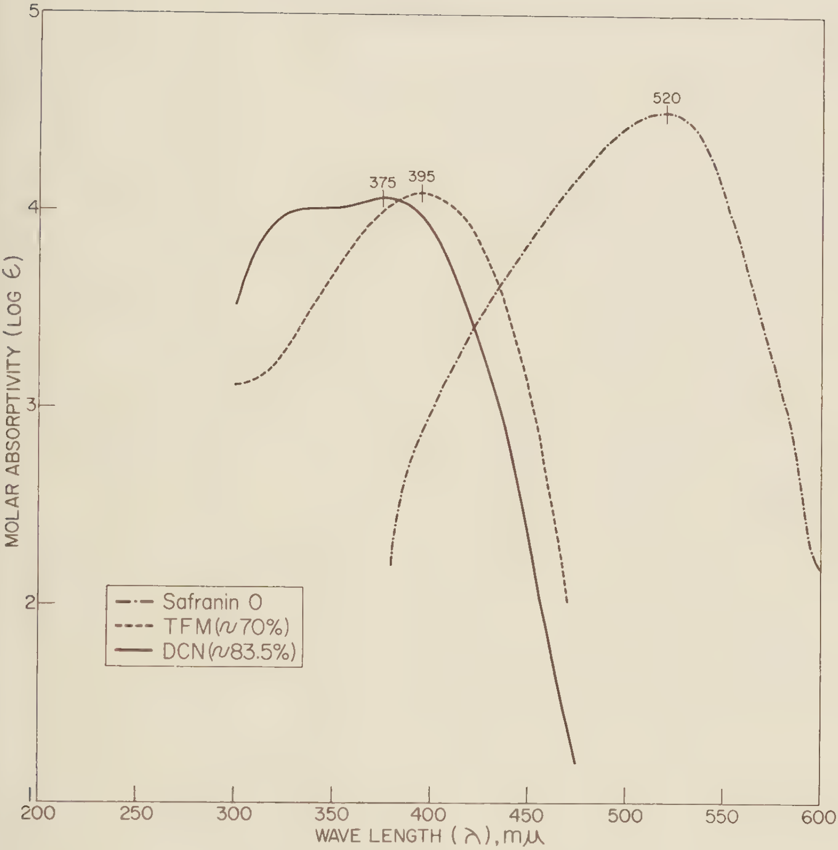
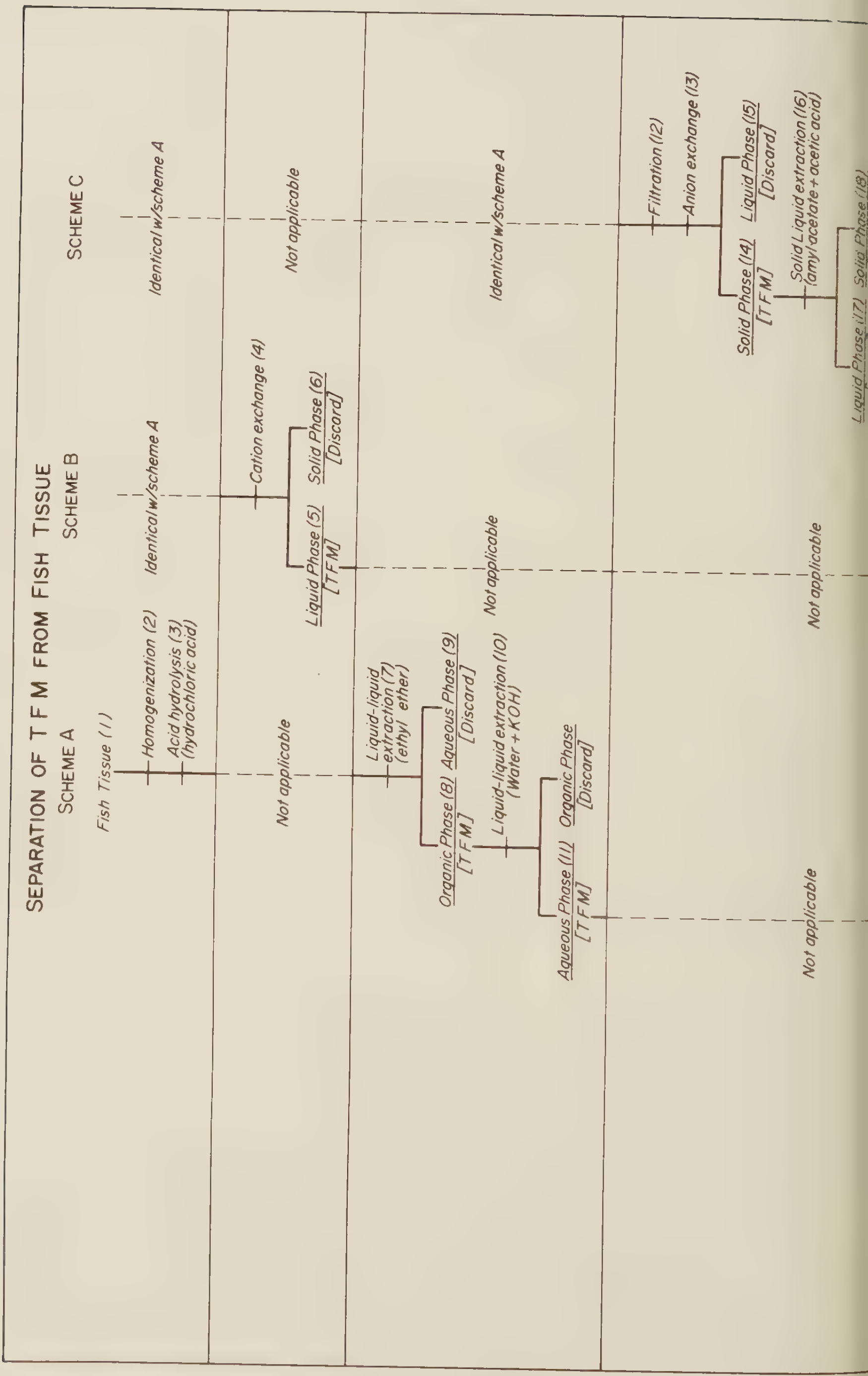


Figure 3.—Visible absorption spectrum of 5,2'-dichloro-4'-nitrosalicylanilide.

2-nitro and 6-nitro isomers. This conclusion was based on the order of elution and the absorption maxima. The spectrum of ortho-nitrophenol is distinct from the meta and para isomers as the maximum absorption is near 415 mμ (Table 1). The absorption maxima of the first two bands eluted from the column were both near 415 mμ. Ortho-nitrophenol migrates 6 to 10 times faster than either the meta or the para isomer when chromatogrammed on silica gel; benzene was the developing solvent and alkaline permanganate was introduced to the columns to detect the position of the phenols (Smith, 1963). A similar behavior of these isomers could be expected in ion-exchange chromatography.

Various components of the technical grade TFM can thus be separated by gradient-elution chromatography with anion-exchange


SEPARATION OF T F M FROM FISH TISSUE

SCHEME A
SCHEME B
SCHEME C
Fish Tissue (1)
Homogenization (2)
Acid hydrolysis (3) (hydrochloric acid)
Identical w/scheme A
Identical w/scheme A
Not applicable
Cation exchange (4)
Liquid Phase (5) [T F M]
Solid Phase (6) [Discard]
Not applicable
Liquid-liquid extraction (7) (ethyl ether)
Organic Phase (8) [T F M]
Aqueous Phase (9) [Discard]
Liquid-liquid extraction (10) (Water + KOH)
Aqueous Phase (11) [T F M]
Organic Phase [Discard]
Not applicable
Identical w/scheme A
Not applicable
Not applicable
Filtration (12)
Anion exchange (13)
Solid Phase (14) [T F M]
Liquid Phase (15) [Discard]
Solid Liquid extraction (16) (amyl acetate + acetic acid)
Liquid Phase (17)
Solid Phase (18)

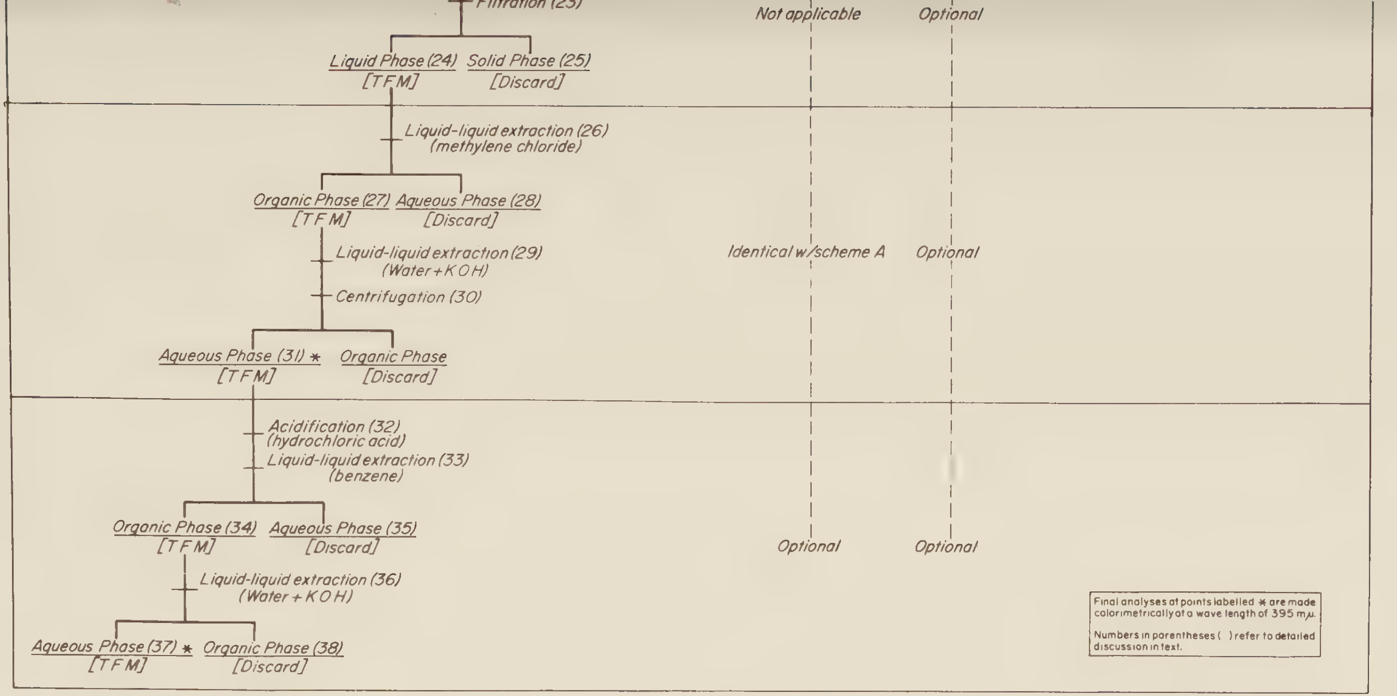

Filtration (23)
Not applicable
Optional
Liquid Phase (24) [TFM]
Solid Phase (25) [Discard]
Liquid-liquid extraction (26) (methylene chloride)
Organic Phase (27) [TFM]
Aqueous Phase (28) [Discard]
Liquid-liquid extraction (29) (Water + KOH)
Centrifugation (30)
Identical w/scheme A
Optional
Aqueous Phase (31) * [TFM]
Organic Phase [Discard]
Acidification (32) (hydrochloric acid)
Liquid-liquid extraction (33) (benzene)
Organic Phase (34) [TFM]
Aqueous Phase (35) [Discard]
Optional
Optional
Liquid-liquid extraction (36) (Water + KOH)
Aqueous Phase (37) * [TFM]
Organic Phase (38) [Discard]
Final analyses at points labelled * are made colorimetrically at a wave length of 395 mμ.
Numbers in parentheses ( ) refer to detailed discussion in text.

Figure 4.—Separation of TFM from fish tissue. Scheme A, solvent extraction; B, cation exchange; C, anion exchange.

resins. At present, only the absorption maxima of compounds producing color in alkaline solutions and their order of elution have been evaluated. Phenolic compounds can be differentiated by infrared analysis (Smith, Applegate and Johnson, 1961). Solutions of TFM (98 percent) in benzene have been measured to as low as 200 ppm concentration. A change of 0.1 in optical density (7.62 $\mu$) corresponded to a change of 1,700 ppm in concentration.

Presence of other isomers, dinitro compounds, and similar reaction products has not been disproved. Until the question of relative composition is answered fully, analysis by visible absorption for 3-trifluoromethyl-4-nitrophenol is limited to its detection as a group of colored compounds whose absorption maxima in alkaline solution are approximately 395 m$\mu$. The crude lampricide formulation will be termed TFM although the 3-trifluoromethyl-4-nitro isomer is believed to be the most selective lampricidal component (Applegate, Howell, and Smith, 1958).

When dilute solutions containing 1 ppm or less of technical grade TFM were passed through a column of anion-exchange resin which was originally peach-colored, a thin yellow band formed at the top of the column. This band started to develop when as little as 50 micrograms of TFM had been adsorbed from solution. Desorption of TFM from the resin was accomplished by passing a small amount of amyl acetate, acidified with acetic acid (approximately 10 percent by volume) through the column. TFM solutions as low as 1 ppb in distilled water were concentrated sufficiently by this method to permit subsequent colorimetric determination of the TFM concentration. Anion exchange, therefore, appears to be applicable in concentrating dilute lampricides. It is expected that this technique will be useful for determining the concentrations of these compounds in natural waters.

Preliminary filtration of natural waters is often required to remove suspended solids that may clog anion-exchange columns. Adjustment of the pH of the samples to 8.5 with potassium hydroxide prior to anion exchange often produced precipitates, principally ferric hydroxide and calcium carbonate. Some naturally occurring organic material may also be coagulated. The precipitated material was removed by passing the collected water, after pH adjustment, through microporous filter disks (Gelman G-5 or Millipore HA, 0.45 $\mu$ pore size). The TFM lost by adsorption on the solids collected on the filter disks is assumed negligible because of the prevailing negative electrical charge.

All samples were adjusted to pH 8.5 with KOH, filtered, and then passed through 1-gram beds of Dowex 1 x 8, 200/400 mesh, OH form, anion-exchange resin. Subsequent elution was made with amyl acetate (acetic acid 10 percent by volume). The column eluate was then extracted into basic water and TFM concentration

Table 2.—Colorimetric analysis of a natural water sampled before, during, and after treatment with TFM[1]

[Stream: Pentwater River, Oceana County, Michigan; basin: Lake Michigan; location: estuary above Pentwater Lake, T16N, R18W, S24]

| Date | Days from treatment date | Before concentration by ion exchange | | After concentration by ion exchange | |
|---|---|---|---|---|---|
| | | Absorbance[2] | Concentration ppm[3] | Absorbance[2,4] | Concentration ppm[3] |
| April 16, 1964 | -1 | 0.000 | 0.000 | 0.0000 | 0.0000 |
| April 17, 1964 | 0 | .078 | 1.31 | .0629 | 1.06 |
| April 20, 1964 | +3 | .003 | .050 | .0002 | .0037 |
| August 20, 1964 | +122 | .000 | .000 | .0000 | .0000 |

[1] All absorbance values are averaged for two determinations except day +122.

[2] Absorbance measured at 395 m$\mu$ blanked against sample taken before treatment commenced (day -1).

[3] Equivalent concentration of technical grade TFM in ppm based on a molar absorptivity of $\epsilon = 12{,}300$ cm$^2$/mol.

[4] Absorbance corrected for tenfold concentration by anion exchange.

measured colorimetrically at 395 m$\mu$. A layer of light-brown material remained adsorbed by the resin. A definite separation was thus effected. A typical analysis of stream samples includes colorimetric measurements before, during, and after treatment with TFM (Table 2). The final absorbance of the sample taken one day prior to treatment (day -1) was very low after pH adjustment and filtration. Measurements of the sample taken during treatment indicate a TFM recovery of approximately 80 percent after anion exchange, elution with amyl acetate-acetic acid, and back-extraction into basic water. A gradual reduction in absorbance has been observed for diluted solutions of TFM stored over a period of time and this factor may be important if such samples are not adequately preserved. The apparent, strong temperature dependency of the ionization constant for TFM also affects the magnitude of color development. The slight absorbance of the sample taken shortly after treatment was completed (day +3) may or may not be significant as a measure of residual TFM. Such low absorbance may only reflect variations in the background color or instrumental changes. A tenfold concentration was effected on the sample for which data are presented. A thousandfold concentration is practical, however, and often is desirable as the absorbance values may be in the extreme low range of the spectrophotometer.

A stream sample collected shortly before treatment is assumed to contain representative amounts of any naturally occurring colors that are present. A water sample taken at any time during treatment will be representative of the amount of chemical present in the water over this period if thorough mixing and uniform treatment concentrations of the lampricides can be assured, and if the uptake of lampricide by the bottom sediments is small compared to the total amount of chemical applied. The lampricide concentration tails off fairly rapidly after treatment is completed and samples taken 6 to 8 hours later must be concentrated prior to colorimetric analysis. A portion of this residium will also include any lampricide that has reversibly diffused into the sediment during treatment when a higher equilibrium concentration exists. The character of the residual concentration as influenced by this latter factor is not completely defined at the present time but its importance is recognized. Further work will be necessary to evaluate this process whereby residual lampricides are slowly released from bottom sediments into the water. Bottom sediments are also being examined for TFM by solvent extraction. Quantitation of the lampricides which have been initially adsorbed or otherwise removed from solution by fish, other aquatic organisms, or bottom sediments prior to analysis is augmented by a knowledge of the relative compositions of the technical grade chemicals introduced into the surrounding waters.

## Solvent Extraction of TFM and DCN in Fish

A suitable technique for the release of the lampricides bound in fish tissues or bottom sediments requires that the TFM first be released into a separated soluble form for colorimetric determination of concentration. Three alternate schemes have been developed for the separation of TFM from fish tissue which are also broadly applicable to bottom sediments (Fig. 4, A,B,C). Numbers in parentheses in the figure refer to detailed discussion in the text.

The initial steps are identical in all three schemes. The fish tissue (1) to be analyzed is first homogenized (2) in water with a high-speed blender. The resulting slurry is hydrolyzed (3) by refluxing for 24 hours in 3 N hydrochloric acid. This hydrolyzed solution of soluble polypeptides, amino acids, insoluble oils, and acid-insoluble humin (Gortner, 1949) has a deep brown color. TFM in aqueous solution is not affected by this acid and heat treatment. Preliminary evidence indicates that the DCN molecule may be split by this severe treatment and the procedure at present is therefore limited to TFM. The hydrolyzed solution is allowed to cool, made up to volume, and aliquots taken according to the scheme employed.

The first scheme (Fig. 4A) is based on classical solvent-extraction methods. The distribution coefficient for TFM between polar and nonpolar solvents depends upon the pH of the solution. No detailed investigations have been conducted to determine the optimum pH range for extraction under these conditions; it appears, however, that an acid range of 2-4 and a basic range of 8-10 (below and above the pKa of 6.07) are suitable for TFM extraction from acid water to organic solvent and from organic solvent to basic water, respectively. In acidic solutions, TFM exists principally in its nonionized form and the distribution coefficient favors the organic solvent, ethyl ether (7). A water-solvent ratio of 10:1 is established and the aqueous acid solution (3) is extracted five times. The aqueous phase (9) is discarded. The combined ethyl ether extracts (8) are then extracted (10) with three portions of dilute KOH (volume ratio 3:1). The basic extracts (11) are combined and then warmed slightly to vaporize the ethyl ether from solution. Warming diminishes the amount of dissolved ether and reduces the possible effects of this solvent on the distribution coefficient of the next solvent-extraction pair.

At this point the basic solution can either be brought up to volume and divided into aliquots, or carried through in its entirety to the next solvent-extraction step. Regardless of the procedure, the solution is again acidified (22) in the same manner as previously stated in the ether-extraction step. The acidified solution is filtered (23) under vacuum with a Büchner funnel and Whatman No. 1 filter paper to remove any insoluble material. The filter paper and particulate matter (25) are then washed several times to insure complete removal of any retained TFM.

The filtered solution (24) is next extracted (26) five times with methylene chloride (volume ratio 10:1). The extracted aqueous phase (28) is discarded. The combined methylene chloride extracts (27) and washings are extracted (29) with dilute KOH in a manner similar to that in the earlier ether extraction. The basic aqueous phase (30) often takes on an opalescent color which prevents direct colorimetric analysis. Phase separation is also frequently hampered and appears to be a function of pH. It is therefore necessary to centrifuge this basic aqueous phase to achieve a good separation (31). Colorimetric analysis can be made at this point if the background color is sufficiently reduced in the blank determination containing fish but not TFM.

A third extraction accomplishes further separation of the lampricides from interfering background colors. The aqueous phase (31) from the previous extraction is first acidified (32) and can be used directly or made up to a measured volume and then divided into aliquots. The third extraction with benzene (33) is carried out in a manner similar to the earlier extractions with organic solvents (34-38), The basic aqueous extraction of the benzene phase is analyzed colorimetrically. In general, this method has achieved good results. The degree of concentration of minute residues is limited, however, by the various solvent proportions.

In the second procedure (Fig. 4B) an aliquot is passed through a prepared column of Dowex 50W x 8, 50/100 mesh, hydrogen form, cation-exchange resin (4). This step removes much of the residual color; material that is insoluble in acid solutions is also filtered out (6). The column is then washed with 3 N hydrochloric acid. Any TFM present passes through the column (5). The tacit assumption is made, however, that no TFM remains bound to the acid-insolubles, which usually constitute a small fraction of the total weight of hydrolyzed tissue, or to the ion-exchange resin. The pH of the solution is highly critical at this stage. If the pH is too low, nonionized TFM tends to "adsorb" onto the cation exchanger or the filtered solids and resists desorption during the subsequent washing with acidified water. This effect limits the general applicability of the test because recovery of the TFM has not always been quantitatively reproducible.

The combined effluents from the cation-exchange column are very faintly colored and still acidic. Under these conditions TFM exists as the nonionized phenol which ordinarily is not subject to cation exchange and is more soluble in nonpolar than in polar solvents. The distribution coefficient between methylene chloride and acidic water greatly favors the organic phase. The aqueous solution which has previously been passed through a cation exchanger is next extracted with several portions of methylene chloride, which is immiscible with and denser than water. The combined methylene chloride extracts are then extracted with several portions of water adjusted to pH 10 with potassium hydroxide. TFM exists principally as the phenolate ion in solutions which are basic to its pKa of 6.07. In this condition TFM is more soluble in a polar than in a nonpolar solvent. If TFM is present in the organic phase, its presence will be dramatically demonstrated by its characteristic yellow color when it transfers to the alkaline water. The distribution between phases in this step so greatly favors the aqueous phase that three extractions may be sufficient for quantitation unless the final concentration is very high or unless the proportion of the phases is extremely adverse.

A third scheme (Fig. 4C), based upon anion-exchange as employed in the analysis of natural waters, combines the best features of the two previous ones. This scheme parallels the solvent-extraction procedure previously described (Fig. 4A) through the ether-extraction step. Suspended particles in the basic extract (11) from the ether extraction tend to produce partial clogging of the resin columns and are removed by passage through sintered glass filters (12) prior to exchange. The filtered solution is then brought up to volume and aliquots are taken to be passed through a column of an anion-exchange resin (13) prepared as follows:

The column containing Dowex 2 x 8, 200/400 mesh, anion-exchange resin in chloride form, is washed initially with distilled water and then with amyl acetate containing 10 percent acetic acid by volume. Conflicting colors that have been produced by the reaction of concentrated mineral acids with amyl acetate necessitate the substitution of acetic acid. Residual colors due to impurities that sometimes remain in the resin after manufacture and which may obscure the analysis are also removed by this washing. A 1 N solution of KOH is then passed through the column to insure conversion of the resin to the hydroxide form. This change is evidenced by a distinct color change from white (chloride form) to peach (hydroxide form). The resin column is now ready to receive the sample solution. The major portions of the colored components in the sample pass through and are not exchanged (15). A light brown color replaces the original peach color of the resin when fish hydrolysates are thus exchanged (14). Both TFM and DCN are exchanged rapidly and if present in sufficient quantity, form yellow bands at the very top of resin columns. These bands are partially obscured, however, if the solutions to be exchanged contain a high proportion of exchangeable fish components.

After a solution containing fish hydrolysate and lampricide is passed through the anion-exchange column, the resin bed is washed with distilled water to remove any residual nonexchanged material. A solution (16) of amyl acetate, acidified with acetic acid (10 percent by volume) is then passed through the moist resin. A large distribution coefficient is evidenced for TFM between resin and amyl acetate under these conditions and the first 50 ml of eluent (17) contains essentially all of the TFM. Some difficulty may be experienced, however, if gas bubbles formed by the reaction between acid and exchanged carbonates disturb the resin column. The acidified amyl acetate selectively desorbs the lampricides and a brownish residue (18) of fish components is unaffected. Desorption of the lampricides from the anion-exchange resin is limited by the rate of diffusion from the interstices of the resin particles and the efficiency of solvent contact. A small-mesh resin and a low flow rate are important for best recovery. The amyl acetate phase is then extracted with basic water (19). The extracted organic phase (21) is discarded. The concentrations of the lampricides thus separated are measured colorimetrically (20) and compared to a fish blank, containing no lampricides, that is carried through the same treatment. Additional solvent extractions with methylene chloride and/or benzene are optional if further separation is considered necessary.

Analysis of bound lampricides in fish tissues by either solvent extraction or by combined cation exchange-solvent extraction requires further refinements to yield quantitative results. Resolution of the problems involved in reducing conflicting background colors in the final extracts and of recovering high percentages of the lampricides is necessary to insure highly sensitive methods. Background color, due to fish components, is reduced greatly in anion exchange as both TFM and DCN are adsorbed selectively by the anion-exchange resin and then desorbed by acidic amyl acetate. The anion-exchange procedure appears to possess the greatest potential for obtaining quantitative separation of lampricides from fish tissues. The procedure is fairly direct and the background color is the lowest of the three techniques followed. All of the procedures considered here are still under investigation, however, and may require modification for different species of fish, types of bottom sediment, or water samples.

## Summary

1. Development of ion-exchange and solvent-extraction methods has been initiated for the analysis of natural waters,

bottom sediments, and fish tissues for the lampricide TFM and its synergistic compound DCN.

2. Natural waters were analyzed directly for their lampricide concentrations by anion exchange followed by elution with selective solvent mixtures.

3. Tissue homogenates of fish to which known quantities of TFM were added in the laboratory were analyzed for bound lampricides. The fish were first hydrolyzed in 3 N HCl; the background color was then reduced either by passing the hydrolysate through ion-exchange resins, by a series of solvent extractions, or by a combination of these techniques.

4. At present, detection and measurement are limited to the colored isomeric compounds present in technical grade TFM which absorb light at 395 mμ. DCN can be determined separately as the safranin dye complex at 530 mμ.

5. The methods employed for separating and selectively concentrating the lampricides to levels that can be determined colorimetrically are based on standard procedures applicable to other similar organic compounds.

## Literature Cited

ANDERSON, R. E., and R. D. HANSEN

1955. Phenol sorption on ion exchange resins. Ind. Eng. Chem., 47: 71-75.

APPLEGATE, VERNON C., JOHN H. HOWELL, and MANNING A. SMITH

1958. Use of mononitrophenols containing halogens as selective sea lamprey larvicides. Science, 127: 336-338.

BRIEGLEB, G., and G. ANGERER

1952. Mesomerism of the nitrophenolate ions from the standpoint of a new effect in light absorption. Angew. Chemi., Bd. 64, S. 685-686.

CHASANOV, M. G., R. KUNIN, and F. McGARVEY

1956. Sorption of phenols by anion exchange. Ind. Eng. Chem., 48: 303-309.

DANIELS, S. L., L. L. KEMPE, E. S. GRAHAM, and A. M. BEETON

1963. Quantitation of microorganic compounds in waters of the Great Lakes by adsorption on activated carbon. Great Lakes Res. Div. Inst. Sci. Tech., Univ. of Mich., Pub. No. 10, pp. 118-123.

EBEL, WESLEY J.

1962. A photoelectric amplifier as a dye detector. Great Lakes Fishery Commission, Tech. Rep. No. 4, pp. 19-26.

GORTNER, R. A.

1949. Outlines of Biochemistry. John Wiley & Sons, Inc., New York. 3rd. Ed., pp. 324-328.

HOWELL, JOHN H., EVERETT L. KING, Jr., ALLEN J. SMITH, and LEE H. HANSON

1964. Synergism of 5,2'-dichloro-4'-nitro-salicylanilide and 3-trifluormethyl-4-nitrophenol in a selective lamprey larvicide. Great Lakes Fishery Commission, Tech. Rep. No. 8, 21 pp.

LANG, L., Ed.

1962. Absorption spectra in the ultraviolet and visible region. Vol. III, Publishing House of the Hungarian Academy of Sciences. Budapest.

MIDDLETON, FRANCIS M., AARON A. ROSEN, and RICE H. BURTTSCHELL

1959. Manual for the recovery of organic chemicals in water. Robert A. Taft Sanitary Engineering Center, Cincinnati, Ohio, 52 pp.

NOLLER, CARL R.

1958. Chemistry of organic compounds. 2nd Ed., W. B. Saunders Co., Philadelphia, pp. 439-444, 507.

PETERSON, SIGFRED, and ELMER GOWEN

1953. Equilibria between aromatic acids and weak base anion exchangers. Ind. Eng. Chem., 45: 2574-2586.

SCHRAUFSTATLER, E.

1962. Chemical development of Bayluscide. Pflanzenschutz-nachrichten "Bayer," 15: 25-33.

SHAPIRO, JOSEPH

1957. Chemical and biological studies on the yellow organic acids of lake water. Limnol. & Oceanogr., 2: 161-179.

1958. Yellow acid-cation complexes in lake water. Science, 127: 702-704.

SMITH, B.

1963. Simple adsorption chromatographic method for the investigation of phenolic structures. Acta. Chem. Scand., 16: 843-848.

SMITH, MANNING A., VERNON C. APPLEGATE, and B. G. H. JOHNSON

1960. Colorimetric determination of halogenated nitrophenols added to streams as sea lamprey larvicides. Anal. Chem., 32: 1670-1676.

1961. Physical properties of some halo-nitrophenols. J. Chem. Eng. Data, 6: 607-608.

STRUFE, REIMER

1961. Field tests for the colorimetric determination of the molluscicide Bayer 73. Bull. World Health Org., Vol. 25, pp. 503-507.

1962. Determination of Bayluscide in field tests. Pflanzenschutz-nachrichten "Bayer," 15: 42-49.

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# Shad On the Move: Cape Fear River

**by James R. Davis* and Paul R. Nichols†**

ONE has only to see the excitement along the Tar River at Rocky Mount during the annual shad derby beginning April 11, or to see the crowded shores and bridges on the Connecticut River in April-May, to realize that fishing for American shad, *Alosa* (Latin for shad) *sapidissima* ("most palatable"), is rapidly developing into an important recreational activity along the Atlantic seaboard.

Shad strike with rattlesnake tenacity and they can snap an 8-lb. line like a rotten rubber band. When this silver demon is hooked, it will jump, run, sound, and still be battling when led into a landing net. Veteran "shadsters" know that these fast swimmers cannot be "horsed" because their mouths are very soft and will not stand too much drag. Allow the fish to have its own way, reeling slowly and easily, keeping a tight line at each run, and gradually guiding it to the surface near the boat and into the net.

Who is really the daddy of this interesting and novel pastime? Just ask any oldtimer, and he generally claims to be the first to take shad with an artificial lure. Every eastern Carolina community has some fisherman who claims to have originated this pastime, or a close relative who was the first. In reality, it was discovered many, many years ago on the Connecticut River that spawning shad could be enticed to strike a plain hook garnished with colored beads or a piece of red flannel. From this discovery the shad sport fishery developed and has expanded to many rivers—Delaware, Susquehanna, James, Pamlico-Tar, Ogeechee, Edisto, St. Johns, just to mention a few. Last spring, Cape Fear River shad felt the sting of darts and spoons for the first time.

Historically, shad ascended the Cape Fear River to Smiley Falls near Lillington, N. C., about 180 miles from the ocean. However, three present-day dams on this river, located 67, 101, and 124 miles above the mouth, prevent anadromous fish from access to the river above during the spawning season except during periods of extended high flow.

Since 1962 the U. S. Fish and Wildlife Service, Bureau of Commercial Fisheries, the North Carolina Wildlife Resources Commission and the U. S. Army Corps of Engineers (Wilmington District), cooperated in field studies to determine the feasibility of using the navigation locks at each of these dams to pass shad and other anadromous species upstream during their spawning migration. During the course of the investigation many questions were asked by potential shad anglers and interested bystanders. This article answers some of the inquiries and will acquaint the reader with an interesting fish and an exciting sport fishery.

AMERICAN shad occur more or less abundantly along the Atlantic Coast from the Gulf of St. Lawrence in eastern Canada to the St. Johns River in Florida, with their center of greatest availability being from North Carolina to Connecticut. They also are found from southern California to southeastern Alaska

**These are American shad. The top fish, a male, is 5 years old and weighed 3.2 pounds. The female, same age, 4 pounds.**

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CENTIMETERS

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**This is a net full of shad and other fish during periodic sampling of their upstream movement through the locks.**

on the Pacific Coast, where they were introduced more than 85 years ago from the Atlantic Coast. Fishery authorities, strangely enough, have attempted to introduce shad into many inland waters in hopes of establishing populations, but have not been successful.

Shad are anadromous, hatching in fresh water, descending to the ocean for most of their nourishment and growth, and returning to the fresh waters to spawn. No one definitely knows by what means shad find their way back to a parent stream, but some piscatorial professors have theorized that odor derived from vegetation and soils might lead them back, or that the young shad may be accustomed to their "home stream's" smell, and thus "remember" the characteristics of their stream as they migrate up or down the coast in preparation for spawning.

The first shad reach the spawning grounds in the Cape Fear River—immediately below the first dam (lock 1) in the main river, from Highway 53 bridge to Tomahawk in the Black River, and from Highway 53 bridge to Tin City in the North East Cape Fear River—about mid-March, and the run usually continues until mid-June. Both males and females reach the spawning grounds in schools. Without any apparent nest building or elaborate courtship, shad release their reproductive cells into the open water. The eggs and young are left to Mother Nature's care.

The young remain in the river until autumn when they make the long journey to the ocean, at which time they are from 3 to 5 inches long.

While in the ocean, shad make many excursions and travel many miles, as far as the coast of Maine, searching for food. After 2 to 5 years of ocean life they reach sexual maturity, and their most important function becomes that of reproduction. Instinctively, they move along the coast, searching out the stream of their birth and moving against the river's current seeking their natural spawning grounds.

During the spawning migration and the stay in the spawning area, adult shad are caught by all forms of apparatus from seines and nets near the coast and lower rivers to sport tackle in the upriver areas.

THE shad is the largest and best known member of the herring family. It is a close relative of the jump-crazy tarpon (*Megalops atlantica*). The shad is a deep-bodied, laterally-compressed, silvery, and sometimes iridescent fish. Its body, with its curious sawedged belly, is relatively large and its fins are small. The female, or "roe" shad, is larger, deeper, and more distended than the male, or "buck" shad. There are no other clear marks distinguishing the bucks from the roes, as in some other fishes during the breeding season. The average weight of Cape Fear River shad is about 2 pounds for buck and 3 pounds for the roe. Some shad in northern rivers are known to go over 10 pounds, but such records are rare.

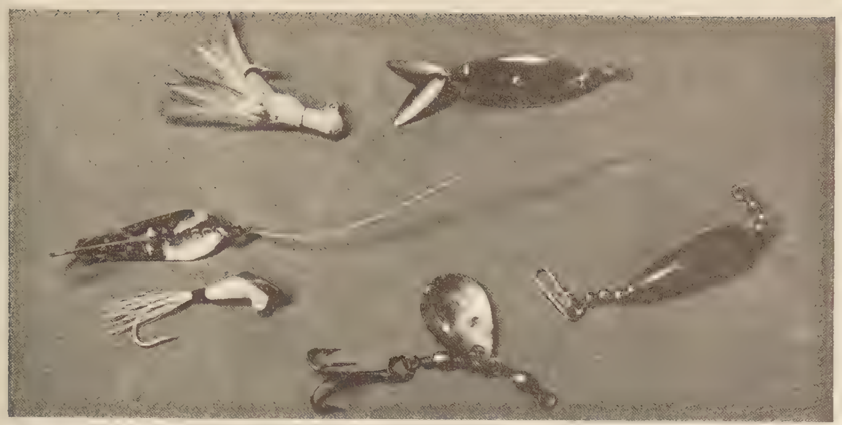
The number of eggs produced by a Cape Fear River shad ranges from 125,000 to 400,000 depending on the size and age of the fish. The fertilized eggs hatch in 3 to 12 days, depending on water temperature—5 days at 63° F.

The young possess teeth with which they are able to eat insects and other small animals and fish. Adults possess no teeth, and they feed largely on tiny microscopic animals called zooplankton which are strained through their many comblike gill-rakers. Shad take little or no food during their spawning migration. Shad that spawn in streams south of Chesapeake Bay, and particularly south of Cape Hatteras, die after spawning. As with many biological questions, the reason is unknown.

Observation of the age distribution by sex of Cape Fear River shad shows that the majority of males are 3 and 4 years old, while the females are 4 and 5 years of age. However, it is not uncommon to find a 2-year-old male or a 6-year-old female. Shad are aged by growth rings (annuli) found on their scales, similar to rings that tell the age of a tree. Still further, when the shad is preparaing to spawn, it gives up eating and ceases to grow. During this period the scale is slightly resorbed, and when growth is resumed after their return to the ocean, as is the case with shad spawning north of Cape Hatteras, it leaves an unmistakable "spawning mark" on the scale.

SHAD are taken by trolling or casting with various types of small metal spoons and weighted jigs. Most casters prefer a single lure, whereas trollers most often use a combination of lures, called a "shad rig", which sometimes results in a double catch. In view of the limited feeding by shad during their spawning migration, when they attack artificial lures, it is more likely a matter of defense of their spawning grounds rather than an offensive for food.

The primary points of shad fishing are to give action to the lure and to keep it as close to the bottom as possible without snagging. Try casting a quarter-ounce shad dart or "triple O" spoon across a submerged bar or at a river bend about a 45-degree angle to the flow of water, reel-



JOEL ARRINGTON

**These lures have proven effective on the American shad and its smaller cousin, the hickory. The sinker holds the spoon down.**

ing in slowly, allowing the lure to reach near the bottom as it swings with the current, slightly pumping the rod to give action to the lure. Or try trolling the river upstream and downstream with a shad dart and spoon combo, throttling down or revving up to keep the lure just off the bottom, swinging across the current on wide turns. Shad often hit while on the swing. The swing also is noted for getting lines tangles and for snagging bottom.

Shad usually keep banker's hours, with peak angling success from 10:00 a.m. to 5:00 p.m., gradually tapering off until dark, and poor between 8:00 a.m. and 10:00 a.m. Regardless of the hours fished, the factors which seem to influence the catches are water temperature and water levels. Catches are usually good between 53° and 75° F., with best catches made at 68° to 70° F. Reduced catches are associated with high or low water levels.

There are no seasonal restrictions on shad fishing with hook and line in North Carolina rivers. Creel and size limits are unrestricted. A valid fishing license is required when artificial baits are used, or when one is fishing outside his county of residence. The Cape Fear river above lock 1 is closed to net fishing. Shad, as with other living things, are capable of self-perpetuation under adequate protection and favorable conditions.

Found in the Cape Fear River is the hickory shad, *A. mediocris,* another member of the herring family, which is very similar in appearance and habit to the American shad. For some real fast and furious action, hit one of these with a fly rod and small spoon. This species is smaller than the American shad, usually weighing from 1 to 2 pounds, and is identified by its jetblack-tipped lower jaw which protrudes the upper. Some fishermen, who can identify these two fish, claim the roe in the "hicks" is much sweeter and better eating than the roe of the other shad. Also, the blueback or glut herring and the alewife or branch herring are often caught in Cape Fear River and misidentified as young shad. However, they are close relatives only, and when reaching maturity average about three-quarters of a pound in weight. On a fly rod either fish will give you more action than a trout twice its size. The gizzard, or stink shad is very abundant in the Cape Fear River but is practically never known to strike artificial bait.

GETTING back to experimental lockage of shad and related species upstream during their spawning migration, last spring about 950 shad and 4,180 herring were passed above lock 1 during 95 hours the lock operated for fish passage. In the spring of 1963, 2,200 shad, 5,450 herring, and 25 striped bass were passed upstream during 166 hours of operation. Historically, more than 10,000 shad were caught per year by bow nets and drift gill nets, fished from the mouth of the Black River to Smiley Falls. Mr. I. A. Matthews, operator of the fish camp at Highway 141 bridge on the Cape Fear, remembers the shad heydays in this area.

Reestablishment of the runs of shad above locks in the Cape Fear River will support expansion of both sport and commercial fishing. Last spring about 259,200 shad entered the Cape Fear River, of which the commercial fishermen caught an estimated 69,250, or about 27 percent. This catch is not of great enough magnitude, at least at the present time, to adversely affect the population.

There is a "rule of thumb" that the restoration of spawning runs of anadromous fish, particularly shad, above barriers in the river would increase future populations of these fish proportionately to the increased spawning area provided. There are about 70 miles of potential spawning and

**Except during periods of extended high flow, the dam at lock number 1 prevents shad from access to the spawning area above.**

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**Survival and growth of young shad hatched above lock number 1 is excellent.**

nursery habitat above lock 1 in the Cape Fear River—thousands of young shad, about 3 to 4 inches long, leaving the river last October from above lock 1, were a sight to behold.

Many sportsmen thought that fishery biologists had been in the sun too long when told that Cape Fear River shad could be taken on hook and line. The moment of truth came to pass when Mr. Rudolph Inman of Elizabethtown, N. C., hooked five beauties below lock 2 in the spring of 1963. Who knows, he may someday be known as "the daddy of Cape Fear River shad fishing." After Mr. Inman pioneered the way, approximately 177 shad were taken last spring between locks 1 and 3 on sports tackle—the area will be open to sports fishing again this spring.

Man's interest in fish has two major phases—food and sport. In the Cape Fear River the shad can satisfy both. They strike like a smallmouth bass, break water like a rainbow trout, and fight to the last gasp. They are delicious in flavor, especially the roe (eggs) smothered with bacon. These are the attributes that make shad so desirable and worthy of conservation.

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# THE OCCURRENCE OF TADPOLES OF THE GREEN TREEFROG, *Hyla cinerea cinerea* (SCHNEIDER), IN TRINITY BAY, TEXAS

By

Richard A. Diener*

The observations reported herein were obtained incidentally to fishery investigations being conducted in Trinity Bay by the Bureau of Commercial Fisheries, U.S. Department of the Interior.

Trinity Bay, the north-eastern arm of the Galveston Bay estuarine system, covers about 96 square miles within the boundaries of Chambers County and is located about 40 miles east of Houston, Texas, U.S.A. Marshlands border the bay on the northern and eastern margins, but those on the eastern side are separated from the bay proper by spoil banks which are the result of the dredging of a navigation channel paralleling the shore. Bluffs 20 feet in height form the western boundaries of the bay. The bay receives fresh water from the Trinity River and from a number of small streams and bayous which are strongly influenced by tidal currents, Salinity has been observed to range from 0.0‰† at the head of the bay near Trinity River to over 20‰ along the southern limits connecting with Galveston Bay. The water temperature has been observed to range from 1.0°C. during the winter months to over 29°C. in late summer. Turbidity is generally greatest in the eastern half of the bay.

Perhaps the most beautiful of all our treefrogs is the green treefrog, *Hyla cinerea cinerea* (Schneider). Adults can be found throughout the spring and summer in the moist woods and swamps, fresh or slightly saline (salinity up to 1.6‰), of south-eastern Texas where they abound.

The occurrence of adults in brackish water habitats is well documented in the literature. Noble and Hassler (1936) found large choruses of this frog on sandy flats in the vicinity of Cove Point and Solomon's Island in Chesapeake Bay, Maryland, where the water was, in all probability, brackish. Dunn (1937) discusses a weakly differentiated population (*H. c. evittata*) which is largely confined to the area of the upper tidewater Potomac River in Virginia. Carr (1940) lists this species as being "occasional" in the Florida mangrove swamps. Burger, Smith, and Smith (1949) found this species about shallow pools of the coastal marshes near Sabine Pass, Texas. Peterson, Garrett, and Lantz (1952) found *H. cinerea* in brackish waters of the Florida Keys. Hardy (1953) found *H. cinerea* near Chesapeake Bay in Maryland, in breeding pools subject to saft spray and with salinity averaging 15‰. Neill (1958) records *H. cinerea* as inhabiting the salt marsh at Merritt Island, Florida, and breeding in large numbers on the causeway across Mobile Bay, Alabama, on a supertidal flat.

On February 1st, 1961, three tadpoles of *H. cinerea* were captured in a 16-foot otter trawl by Anthony Inglis and Charles H. Koski. Two of the tadpoles, both 42 mm. long, were taken near Amerada Oil Well No. 1 in open waters 9 feet deep with a salinity of 0.1‰ and a temperature of 7.4°C. The Amerada Oil Well, situated within State of Texas Tract No. 66 in the couth central portion of the bay, is located about 4.4 miles southeast of dry land (Umbrella Point) and 6.5 miles west of the nearest appreciable source of fresh water, Double Bayou. The third tadpole, 43 mm. long, was taken near Tidewater Oil Well No. 1 in open waters 10 feet deep with a salinity of 8.3‰ and a temperature of 8.1°C. The Tidewater Oil Well, situated within State of Texas Tract No. 113, is located along the southern limits of the bay equidistant (5.2 miles) between Houston Point to the north-west and Smith Point to the south-east, and lies about 10.1 miles south-west of Double Bayou. During collections, the water was rough and turbidity high at both locations.

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* Contribution No. 187, Bureau of Commercial Fisheries Biological Laboratory, Galveston, Texas, U.S.A.

† Salinity in parts per thousand is represented by the symbol ‰.

The colouration of the head and body of the tadpoles in preservative is dark brown, but becomes pale grey on the ventral surface. The lateral surfaces of the tail are pale brown in colour. Paired pelvic limb buds about 1 mm. long are visible on the three specimens.

## REFERENCES

Burger, W. Leslie, Philip W. Smith, and Hobart M. Smith (1949). Notable records of reptiles and amphibians in Oklahoma, Arkansas, and Texas. Jour. Tennessee Acad. Sci., 14 (2): 130-134.

Carr, Archie F. (1940). A contribution to the herpetology of Florida. Univ. Florida Pub., Biol. Sci. Ser., 3 (1): 1-118.

Dunn, E. R. (1937). The status of *Hyla evittata* Miller. Trans. Biol. Soc. Washington, 50: 9-10.

Hardy, Jerry D. (1953). Notes on the distribution of *Mycrohyla* [sic] *carolinensis* in southern Maryland. Herpetologica, 8 (4): 162-166.

Neill, Wilfred T. (1958). The occurrence of amphibians and reptiles in saltwater areas, and a bibliography. Bull. Marine Sci., Gulf and Caribbean, 8 (1): 1-97.

Noble, G. K., and W. G. Hassler (1936). Three salientia of geographic interest from southern Maryland. Copeia, 1936 (1): 63-64.

Peterson, Harold W., Ronald Garrett, and John Perry Lantz (1952). The mating period of the giant tree frog *Hyla dominicensis*. Herpetologica, 8 (3): 63.

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# TEXAS ESTUARIES AND WATER RESOURCE DEVELOPMENT PROJECTS[1]

by

**Richard A. Diener**

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The Gulf coast of Texas is a broad arc of approximately 375 miles, extending from Sabine Pass to the mouth of the Rio Grande. Throughout its much embayed length, this coastline passes through a variety of climatic regions, ranging from the humid zone (55 inches or more of precipitation) of the eastern portion of the semiarid zone (25 inches or less) of southern Texas (Fig. 1).

The embayments, called estuaries, represent ecotones or "buffer zones" between the fresh water of the river systems and the salt water of the sea. As such, estuaries have physical, chemical, and biological characteristics which are unlike those of either the fresh or oceanic waters. They are rich in fauna and, in many instances, represent resources which support major commercial and sport fisheries. Unfortunately, these estuaries are being destroyed or modified by an ever-increasing number of water development and construction projects.

The purposes of this paper are to: (1) outline some of the typical characteristics of estuaries; (2) show the importance of the estuarine fauna to commercial and sport fisheries of the coastal waters of Texas; and (3) describe changes within the estuaries attributable to water development and construction projects.

## ESTUARINE CHARACTERISTICS

Several definitions have been proposed for estuaries by various scientists having different professional interests. For our purposes, however, the definitions of Tully and Barber, Ketchum, and Reid are sufficient. Tully and Barber (1961, *In* Mary Sears, Oceanography, *Am. Assoc. Advancement Sci. Publ.* 67, p. 19) state that the basic requirement for the establishment of an estuarine system in any region is the presence of a supply of fresh water which exceeds losses by evaporation or freezing. Ketchum, (1951, *J. Marine Res.* 10(1): 19) and Reid (1961, Ecology of inland waters and estuaries, Reinhold, N. Y., p. 69) both define an estuary as a body of water in which river water mixes with, and measurably dilutes, sea water. Estuaries are also defined as the wide mouth of the river or arm of the sea where the tide meets the river currents, or flows and ebbs.

Estuaries are usually, though not always, semienclosed bodies of water. Hydrological conditions described above are often found far offshore from the mouths of large rivers. Estuaries along the Gulf coast and especially Texas, result from the formation of offshore bars across drowned river mouths, although in other areas they frequently occur in deltaic formations. The shorelines bordering the landward margins of Texas estuaries are usually composed of both Pleistocene and Recent sediments, while the offshore bars usually consist of Recent sediments.

The estuaries (and coastal lagoons) of Texas, covering a total of approximately 1,200 square miles, range in size from about 70 square miles (Sabine Lake) to about 530 square miles (Galveston Bay and adjacent waters). In general, the estuaries are oval or funnel shaped and most have dimensions of less than 15 miles, whereas the coastal lagoons (represented in Texas by the Laguna Madre with an area of approximately 490 square miles) are oblong and parallel the coast. Furthermore, both have cross-sections that reveal shallow, depression shapes frequently transected by oyster reefs or sand bars. Their average depths are usually less than 10 feet. Shepard (1953, *Bull. Am. Assoc. Petroleum Geol.* 37(8): Fig. 1), in a comparison of unpublished soundings of Texas bays made by the U. S. Coast and Geodetic Survey during the years 1854-75 and 1933-35, found that those bays which have rivers that dump large amounts of sediments into them showed considerable shoaling, whereas those having no large rivers emptying into them actually deepened or remained the same.

Data from U. S. Coast and Geodetic Survey Tide Tables indicate that Gulf tides are of small amplitude, generally less than 2 feet. Irregular changes of water level of greater amplitude are generally caused by wind-driven currents. Wind-driven currents are important for maintaining circulation patterns in the estuaries and for

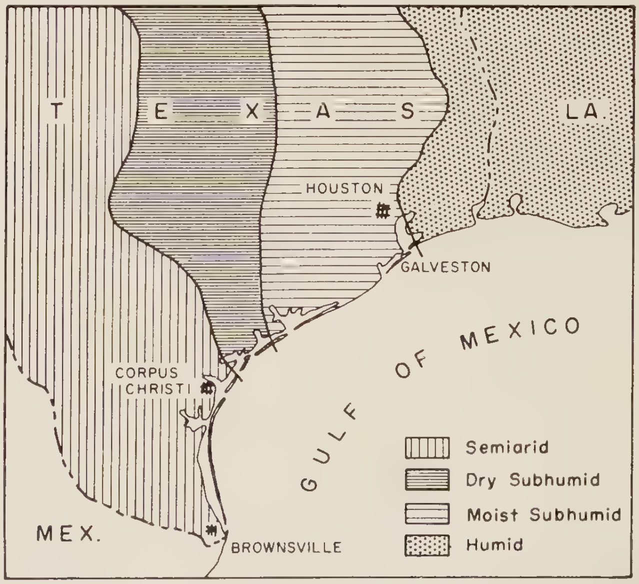

*Figure 1. Climatic zones of Texas (Modified after Thornthwaite, 1948, Geogr. Rev. 38(1): Pl. 1).*

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[1] Contribution No. 199, Bureau of Commercial Fisheries Biological Laboratory, Galveston, Texas.

*Figure 2. Salt marshes near Cameron, Louisiana. Marshes such as these extend into Texas and are rich storehouses for nutrients, vitamins, and organic detritus which are so vital in maintaining the estuarine habitat.*

stirring much of their bottoms, redistributing nutrient materials.

Since the turbidity of Texas estuaries generally ranges from moderate to high, much of their volume does not receive the full effects of sunlight. Consequently, phytoplanktonic (floating plant) forms such as simple algae make up the bulk of the producers (organisms that synthesize protoplasm from inorganic compounds by photosynthesis) in estuarine waters, there being few submerged rooted aquatic plants. However, emergent plant growth of such forms as canes, rushes, and sedges, which constitute the dominant species of the salt marshes, is considerable in shallow waters relatively free of strong wave activity.

Salt marshes form much of the periphery of many northern Gulf estuaries, especially those east of the Sabine River (Fig. 2). They represent an ecotone between dry land and the low water level of the estuary. Many estuarine animals utilize portions of the marshes for feeding and nursery areas. Nutrient materials such as phosphates and nitrates which are vital in maintaining the estuarine community are flushed from the marshlands in large amounts by tidal action. Starr (1956, *Ecology* 37(4): 658-664) describes the importance of these areas for vitamin $B_{12}$ production and many workers have shown this vitamin to be essential for growth of phytoplanktonic organisms.

Productivity in estuaries is often greater than that of open oceans and the continental shelf and frequently exceeds certain agricultural areas, grasslands, and shallow lakes (Table 1). Productivity is generally greatest during the summer months and daylight hours. Generally, primary consumers (herbivores or omnivores such as shrimp, filter-feeding mollusks, and certain fish) are more numerous in the estuary during the summer months. The addition of fertilizers, such as commercial preparations or sewage, can increase the rate of productivity, but frequently to the detriment of the community in general if not properly planned. This will be discussed briefly in another section.

**TABLE 1**

**Distribution of primary gross productivity. The range of values found in major environments of the world (modified from Odum, 1959, Fundamentals of ecology, W. B. Saunders, Philadelphia, Table 8).**

| Types of ecosystems | Range of average gross productivity g./M$^2$/day |
|---|---|
| Deserts and semiarid grasslands | Less than 0.5 |
| Open oceans (probably also deep lakes) | Less than 1.0 |
| Continental shelf ocean waters, shallow lakes and ponds, average forests, moist grasslands, and ordinary agriculture | 0.5 to 5.0 |
| Coral reefs, estuaries, some mineral springs, semiaquatic and terrestrial communities on alluvial plains, evergreen forests, and intensive agriculture | 5.0 to 20.0 |
| Maximum rates which may be maintained for short periods in the more productive natural and cultivated ecosystems (including polluted bodies of water) | Up to 60.0 |

In shallow estuaries, changes in water temperature occur rapidly; summer temperatures as high as 38° C. and winter temperatures as low as 3° C. have been recorded in Galveston Bay by members of our laboratory staff. Changes of 20° F. (about 11.2° C.) within 5-day periods are common in the winter (Skud and Wilson, 1960, *Trans. Twenty-fifth N. Am. Wildl. Conf.*, p. 322-323), and Gunter (1941, *Ecology*, 22(2): 203-208) states that rapid drops in temperature—one as great as 40° F. within a 4-hour period—resulted in the death of millions of marine organisms.

Two basic salinity types are represented by inshore bodies of water surrounding the northern Gulf: (1) the hypersaline coastal lagoon in which salinity ranges upwards from the recognized 35‰[2] of standard sea water to 80‰ or higher, and (2) the estuary in which the salinity ranges from less than 1‰ at its headwaters to between 20‰ and 35‰ at its mouth. If the definitions given previously are to be followed, bodies of water belonging to the first group are not true estuaries even though they are frequently referred to as such; their high salinity values are generally due to small amounts of stream discharge coupled with high evaporation/precipitation ratios.

The inflow of fresh water is one of the principal sources of dissolved nutrients in Gulf estuaries. Freshwater discharge varies from practically none in the Laguna Madre with no permanent streams entering it, to the tremendous flow of the Mississippi River. Nash (1947, *J. Marine Res.*, 6(3): 169) states that the relationship of growth among estuarine phytoplankton—the basic producer of the estuarine habitat—to terrigenous nutrients is shown by their increase in numbers following periods of heavy rainfall.

In addition to nutrients carried to the estuary by tributary streams, tidal flow transports considerable amounts of organic detritus into the estuaries from adjacent marshes and marine minerals from the sea. Detritus is the principal food of many estuarine organisms. This material is also decomposed by bacteria and fungi, releasing in the process large amounts of organic and inorganic substances which are, in turn, absorbed by estuarine organisms via the aquatic medium.

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[2] **Salinity in parts per thousand is represented by the symbol ‰.**

## THE ESTUARINE FAUNA

The estuarine ecotone or "buffer zone" between the fresh water of the river system and the salt water of the sea is a transition zone of tension, having sharp gradients in which outposts of the freshwater and oceanic animals —or communities of such—maintain themselves in environments that are increasingly unfavorable. Likewise, ecotones between dry land and the estuary proper—such as the salt marsh or bare beach—exist in varying proportions in Texas as one proceeds from Sabine Pass to the Rio Grande. Regardless of the form which the ecotone may assume, the tension encountered by an estuarine organism may result chiefly from its struggle with physical conditions and/or from direct competition with other species from one or both bordering communities. For example, at the border of a grassland community and a salt marsh, the grasses may compete directly with marsh reeds for sunlight, nutrients, and other necessities of life in such a manner that one plant type yields to the other. In such a situation and in areas where the controlling physical factors change rapidly, the transition between communities is usually abrupt and the zone narrow. In opposite circumstances, the transition between communities can be gradual and the zone wide.

In the ecotone, physical influences are different from, and usually intermediate between, those existing within either of the bordering communities. These or other conditions—food or shelter—may be superior in parts or all of an ecotone for certain species and, as a result, various kinds of plants or animals not occurring, or relatively rare, in the bordering communities may become abundant in the ecotone. For example, Ladd (1951, *Publ. Inst. Marine Sci.* 2(1): 137) and other workers found that the numbers of molluscan species is greater in parts of bays having salinity ranging between 15‰ and 31‰ than either in the Gulf (salinity over 32‰) or in portions of bays and headwaters having a salinity generally less than 15‰. This fact is referred to as the *principle of edges* (Clarke, 1954, Elements of ecology, John Wiley, N. Y., p. 412). Conservation officials and wildlife managers have become increasingly aware of this principle and are making efforts at increasing the amount of available ecotone having superior food, cover, and water since this usually favors increased populations of desired game birds and mammals. However, the area of estuarine and marshland ecotones is fixed and, unfortunately, is gradually being destroyed or altered to meet the needs of a growing population and an expanding industrial and agricultural economy.

All plants and animals tend to grow, reproduce and disperse until checked by some influence of the environment. The factor that first stops the growth or spread of an organism is called the *limiting factor*. This concept was first formulated by von Liebig as early as 1840 (1862, Die Chemie in ihrer Anwendung auf Agricultur und Physiologie, 7. Aufl., Friedrich Bieweg, Braunschweig, 2: 225) as the *"law" of the minimum* and was based on nutritional requirements of plants. Later workers have expanded the principle to include factors other than nutrients (heat, light, salinity, etc.) and to include the time element.

It should also be recognized that too much of a given factor can be just as limiting as too little. Consequently, the general principle of the law of the minimum was extended to include the maximum and was restated by Shelford (1913, Animal communities in temperate North America as illustrated in the Chicago region, Univ. Chicago Press, Chicago, p. 302-304) as the *law of toleration.* For greater clarity, this law may be restated in the following manner: as any environmental factor approaches either the upper or lower limit of toleration for a given species, that factor becomes of increasing importance in controlling the functioning, the growth, and even the existence of the individual members of the species.

Since organisms in the estuary are subjected to a continually fluctuating environment, they must possess wide tolerances, generally physiological or behavioral, to the factors involved. If they do not, they either perish or become reduced in numbers and/or restricted in distribution. Organisms lacking wide tolerances to environmental conditions are those affected most when adverse changes occur in the habitat.

In the estuary, salinity is an example of an environmental factor which restricts the distribution of animals, chiefly through interactions with physiological processes. Figure 3 shows a hypothetical relationship between three populations of organisms: two stenohaline (narrow tolerance range for salinity) and one euryhaline (wide tolerance range). The extent to which stenohaline organisms from either the fresh water or oceanic habitats can invade the estuary, and the ability of certain euryhaline species to permanently occupy the estuarine ecotone, depends upon the tolerance of each organism to variations in salinity. The physiological background of these problems is too complex to discuss here, but it can be found in many textbooks on comparative physiology.

Salinity not only directly affects estuarine animals, but indirectly as witnessed by studies on oyster mortality. High salinity alone does not cause death but permits

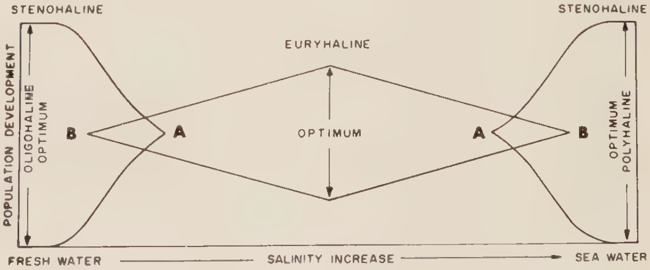

*Figure 3. A schematic comparison of population development of stenohaline and euryhaline organisms. Minimum limits are shown by "A" and maximum limits by "B." Note that stenohaline organisms may be either low salinity tolerant (oligohaline) or high salinity tolerant (polyhaline), and that population development is often affected by slight changes in salinity (modified after Reid, 1961: Fig. 13.2).*

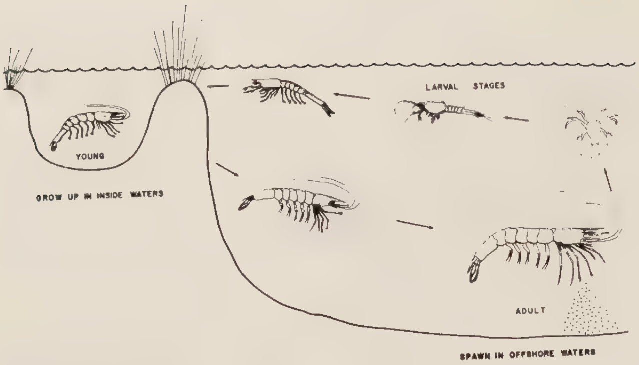

*Figure 4. Generalized life cycle of the edible or commercial shrimp* (Peaneus).

infestations and/or infections of shell pests, predators, parasites, and diseases. In moderately high salinity waters, the incidence of oyster mortality from these causes is much reduced. Thus, salinity *per se* does not appear to be the exclusive regulator.

Species found within the estuary can be separated into two general categories—incidentals and estuary-dependent. Incidentals are species from the fresh water or oceanic habitats which venture into the estuary either by accident or to feed for short periods and which then return to their original habitats or perish. Estuary-dependent species are those which utilize the estuary during part or all of their life cycles for such purposes as breeding, feeding, or developing into juveniles or subadults. This latter purpose is why estuaries are frequently referred to as "nursery grounds."

Skud and Wilson (1960: 321) state that the estuary-dependent species can be separated further into two basic categories—transients and residents. The majority of the more abundant forms are transients and are represented by fishes such as the menhaden *(Brevoortia)* and the mullet *(Mugil)* and by invertebrates such as the edible or commercial shrimp *(Penaeus)*. These particular species may be referred to as "semicatadramous" in that the adults spawn offshore and young move inshore to less saline waters. The oyster *(Crassostrea)* characterizes the residents which spend their entire lives within an estuary.

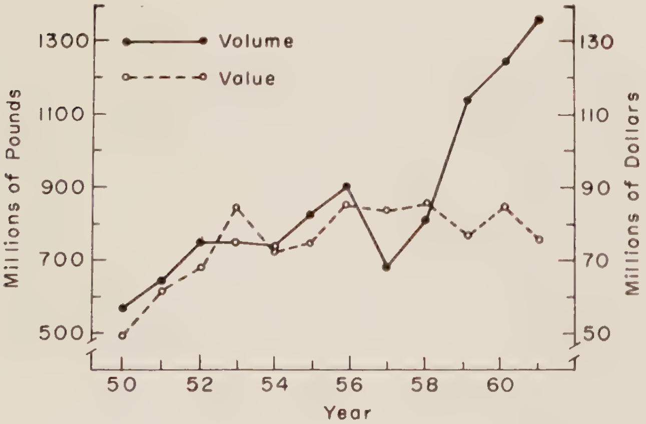

*Figure 5. Gulf coast commercial fishery landings, 1950-61.*

The life history of shrimp *(Penaeus)*, a typical transient, has been described in varying details by many workers, but the following outline should suffice for our purposes. Figure 4 shows the generalized life cycle of this shrimp. Adults spawn offshore and the postlarvae enter the estuaries through passes between the offshore bars and islands and move into the estuarine nursery areas. These nursery areas are frequently secondary or tertiary bays (as opposed to primary bays adjacent to the tidal passes), marshes, bayous, and tide-influenced portions of the large rivers. In a few weeks, following growth and development into juveniles or subadults, the shrimp migrate through the passes and return to the Gulf.

Like the brown shrimp, the life cycle of the oyster *(Crassostrea virginica)* has also been described by many workers. A resident species of the estuary, the oyster generally spawns in the bays during the warmer months. The eggs and larvae develop rapidly and within a few weeks must find a suitable surface for attachment. If successful, they become permanently attached adults. Due to its ability to withstand severe changes in environmental conditions, the oyster is a successful species in many Gulf estuaries.

The shrimp and the oyster present two greatly contrasting pictures with respect to salinity tolerance. The oyster, euryhaline throughout its entire life, is the opposite of the shrimp which is euryhaline during its life in estuarine waters and stenohaline for oceanic salinity during its adult and larval stages. There are, however, many individual and specific variations to this general scheme among the shrimp.

## THE COMMERCIAL FISHERY

Data from the U. S. Fish and Wildlife Service's Statistical Digests for the 14-year period from 1950 through 1963 show that commercial fishing on the Gulf coast has undergone a tremendous expansion. Landings in the Gulf states have increased from a total of 570 million pounds with a value of $50 million in 1950, to over 1,377 million pounds representing a value of $76 million in 1961 (Fig. 5). In 1950, this fishery accounted for 11 and 14 percent of the total U. S. poundage and value, respectively, but increased to 26 and 20 percent for these respective items in 1961. Preliminary figures for 1963 are still higher, with yields totaling 1,387 million pounds valued at $99 million representing 29 and 26 percent, respectively, of the total poundage and value of the U. S. Harvest.

Texas landings paralleled the data for the Gulf coast during the same period (Fig. 6). Landings increased from 97 million pounds valued at $11 million in 1950 to over 203 million pounds valued at $24 million in 1961. The 1961 landings ranked Texas second only to Louisiana on the Gulf coast in terms of poundage, but first in value. During the same year, Texas ranked 10th nationally in poundage and 5th in value of the landings. This high rating in terms of value is due primarily to the large harvest of the brown shrimp. The first-place national ranking of Louisiana in terms of poundage is due to an increasing utilization of menhaden for oils and meals. Harvests of these and other species are expected to increase in the future.

The contribution of the estuaries to these valuable fisheries is well known. Estuary-dependent species account for approximately 98 percent by weight (Diener, 1963, *In* U. S. Fish and Wildl. Serv. Cir. 161, p. 52) and about 90 percent of the value (Skud and Wilson, 1960: 320) of Texas commercial landings. The vast majority of species represented in the commercial fishery are transients, the only resident of any significance is the oyster. The same generalization holds true for most sport fisheries in Texas coastal waters.

It should be emphasized that not all estuarine species enter the commercial fishery harvest. Many species occupying lower trophic levels of the various food chains, especially the herbivores, form the bulk of the diets of such sought-after species as the sand seatrout *(Cynoscion arenarius)* and the southern flounder *(Paralichthys lethostigma)* (Reid, 1955, *Texas J. Sci.* 7(4): 446, 448), and must, therefore, receive equal consideration with the commercially important forms.

## MAN-MADE CHANGES

We have only briefly described the estuarine environment, its characteristics, its fauna, and the subsequent contribution of this fauna to the commercial fisheries of the Gulf coast, with especial reference to Texas. Many will probably ask, "What does all of this have to do with the central theme of this conference—'Water Quality and Chemicals: Industrial and Agricultural'?" The answer is this: a basic knowledge of estuarine biology is essential before we can understand the problems associated with maintaining suitable quality habitat in the estuary, particularly since this habitat is subject to alteration by reduction of fresh-water discharge and introduction of agricultural and industrial chemicals. The myriad of engineering projects in the estuaries and their watersheds further complicates the problem.

We do know that naturally occurring prenomena which alter the *status quo* of the estuarine ecotone, such as droughts, floods, rapid temperature changes, and hurricanes, frequently have adverse effects upon estuarine fauna. Some of these effects are often reproduced, though usually on a small scale, by man-induced alterations associated with a growing population and expanding economy.

The effects of such projects as impoundments and diversion channels on river basins draining into the estuaries and dredging and channelization in the estuaries themselves are many and varied. Even though the effects of these projects cannot always be accurately evaluated, several types of changes may be foreseen. One of the most obvious alterations of existing estuarine conditions is caused by the reduction of fresh-water discharge through greater consumptive water use and increased total evaporation, due to more exposed surface area in reservoirs. A reduced discharge of fresh water could alter the suitability of certain areas to fish and crustaceans by raising salinity; by varying salinity, circulation, and water interchange patterns; by draining surrounding marsh areas; by reducing silt loads and thus altering deposition rates; and by reducing inflow of terrigenous nutrient materials required for primary productivity. Controlled fresh-water discharge, on the other hand, may benefit the estuarine habitat by providing water at periods when it would most benefit the fauna or by leveling peaks and dips represented by flood and drought periods.

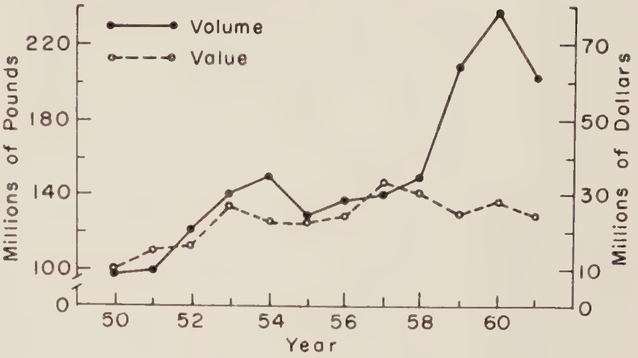

*Figure 6. Texas commercial fishery landings 1950-61.*

A further indication of an expanding economy along the Texas coast is the increasing number of navigation channels, oil wells and associated structures, and general construction projects which alter the quality of fishery habitat in the estuaries to varying degrees (Figs. 7, 8, 9).

Navigation projects, many of which are associated with the Gulf Intracoastal Waterway, often restrict water circulation and interchange by segmenting the estuary with channels and spoil banks. A physical loss of desirable habitat also occurs and resulting siltation can kill oysters by suffocating them. Channelization has become a major problem in Louisiana where alteration of natural drainage systems is facilitating salt-water intrusion and rapidly changing marshland ecology. This is a growing problem in Texas also. Channelization, unfortunately, includes not only dredging, but frequently realignments and repeated maintenance. Even so, with proper planning, adverse effects from channelization can usually be considerably reduced.

Oil wells and associated structures and general projects—a term embracing such items as small fills and bulkheads, wharf construction, pipeline crossings, loading facilities, etc.—usually have minimal effects

*Figure 7. View of the Gulf Intracoastal Waterway near Aransas Pass, Texas. Channelization and the subsequent placement of spoil results in segmentation of the estuaries causing loss of habitat and alteration of water circulation.*

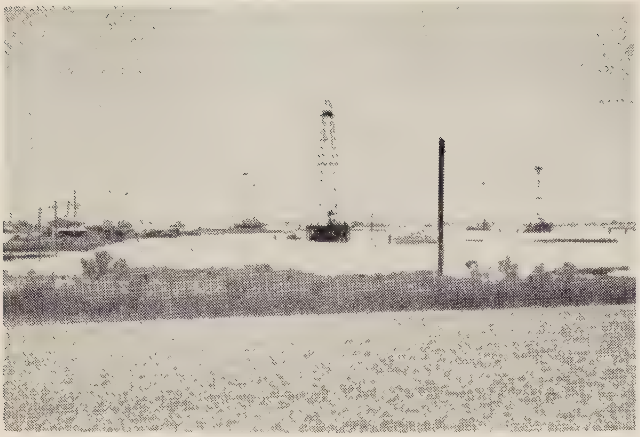

*Figure 8. Oil field in Tabbs Bay, near Baytown, Texas. Oil wells are an example of several projects which, on an individual basis, have minimal effects upon the estuarine habitat, but which may produce serious cumulative encroachments when considered in large numbers.*

upon the estuarine habitat when considered on an individual basis. In large numbers, however, they may produce serious cumulative encroachments upon valuable and irreplaceable estuarine habitat.

There is considerable irony associated with many of these small projects. Bulkheads and their fill, marinas, fishing piers, and other similar structures designed to facilitate the harvest of many species of fish and crustaceans by both commercial and sporting groups often alter or even destroy valuable bay bottom and shorelines used by these same species. Siltation resulting from improper shell dredging can also kill oysters.

What is being done to preserve our estuarine areas from damage caused by the smaller, but numerous projects? When such a project is to be built in navigable waters of the United States, the sponsor must obtain a Department of the Army Navigation permit from the Corps of Engineers. The Fish and Wildlife Coordination Act (48 Stat. 401, as amended; 16 U.S.C. 661 *et seq.*) provides the legal framework for the U. S. Fish and Wildlife Service to review such permit applications before construction. This same legislation also provides for the U. S. Fish and Wildlife Service to review all Federal water development projects.

*Figure 9. Shell dredging in Nueces Bay, Texas. Siltation from improper dredging operations can kill oysters.*

The Branch of River Basin Studies of the Bureau of Sport Fisheries and Wildlife, working with the appropriate state conservation agencies and the Bureau of Commercial Fisheries whenever commercial fishery resources are involved, conducts surveys and prepares detailed reports on projects which could adversely affect fish and wildlife resources. These reports assess the fish and wildlife resources involved, the extent of potential project damage and frequently recommend measures that, if incorporated in a particular project, would eliminate or reduce anticipated damages. Occasionally, such measures actually benefit the resources.

It has been said that Texas, with its arid west supporting a predominately irrigation agriculture and its humid industrialized east, represents a microcosm in which the entire range of nationally important water problems occur (Kneese, 1963, *Proc. Eighth Ann. Conf. Water for Texas*, p. 7). As such, the problems of water supply are many and complex. Consequently, the Bureau of Reclamation's Texas Basins Project was developed.

The Texas Basins Project, presently in the planning stage, is an integral and significant segment of an overall state-wide water supply plan which would provide for developing and delivering adequate water to meet estimated municipal and industrial requirements in the year 2010 and to develop new irrigation with waters not otherwise utilized. The overall plan is basically the plan adopted by the U. S. Study Commission—Texas.

This important project includes proposals to construct numerous upland reservoirs as well as a water transport canal to divert the flow of principal streams in east and central Texas to semiarid portions of southern Texas. Such a plan would provide water for potential municipal, industrial, and irrigational demands, but would greatly reduce tributary discharge into most Texas estuaries and, unless modified, could adversely affect the quality of estuarine habitats. During drought years, this reduction could become critical, especially in view of other water demands which are expected in the future, since it is also apparent that nonproject reservoirs would divert much more water than the Texas Basins Project. Thus, the Texas Basins Project would, from the standpoint of lowering the quality of habitat for fishery resources, compound an already critical problem.

It is presently estimated that projects not associated with the Texas Basins Project will reduce the present average annual tributary discharge of 26.5 million acre-feet into Texas estuaries by about 35 percent by 2010. High salinities frequently found in the estuaries and Coastal lagoons of western and southern Texas would be found in many more estuaries of Texas and smaller harvest values per unit of area typical of those estuaries would be characteristic of many more.

The Texas Basins Project, unless modified, would further reduce tributary discharge which could result in additional losses to coastal fishery resources. Populations of shrimp, oysters, crabs, and several fishes would be subjected to a reduction in numbers and/or restriction of suitable habitat if not wholesale depletion in several estuaries during periods of drought.

The graduated reductions in fresh water would also be detrimental to various recreational fisheries since many sport fishes are estuarine-dependent and nearly all are transients.

The detrimental effects resulting from reduced tributary discharge could be intensified through the introduction of toxic pesticides and herbicides into the estuaries through return flows from adjacent irrigation units. These chemicals, the number of which is continually increasing, have many varied uses depending primarily on the types of undesirable animal or plant that is to be controlled or eradicated. Unfortunately, it is not known what types or in what quantities these chemicals will enter the estuaries.

Equally variable are their known effects on aquatic organisms. Some have been shown to have no effects on test organisms in the laboratory, while others are lethal to all organisms with which they come into contact. Still others show a toxicity to a given species or particular age groups within a given species. This is a field which is relatively unexplored and has many opportunities for both basic and applied research.

The problems posed by industrial and municipal wastes in the form of return flows are just as complex as those of pesticide and herbicide introduction. The problems in the future will be more vexing in that the quality of these return flows will generally be unknown. We do know what happens when treated or untreated sewage or certain industrial wastes are introduced to a body of water, usually fresh. We have seen that pollutants (especially sewage) increase primary productivity above normal levels (Table 1), which can be either beneficial or detrimental to the community as a whole. If too much sewage is added, primary productivity could assume great proportions known as "blooms" which are capable of altering the carbon dioxide and oxygen cycles within a community. Such a phenomenon has been known to result in large fish kills similar to those created by rapid temperature changes or by the toxins of the "red-tide" organism found in the Gulf of Mexico. Other wastes are capable of taking oxygen and other materials which are vital to the maintenance of the estuarine habitat from the water and forming new compounds, many of which have unknown properties.

At the present time, wastes are being dumped into small bodies of estuarine water such as Clear Lake north of Galveston, Texas. This body of water is extremely valuable as a nursery ground for commercial shrimp and as a feeding and nursery ground for many species of fish. With an increasing population, however, pollution has increased in recent years and several kills of menhaden have been reported. The condition of Clear Lake is expected to worsen as the population continues to increase.

A few of the more obvious methods of lessening the detrimental effects of these pollutants upon the estuaries appears to be diluting return flows with more water, treating the sewage and other wastes, and dispersing the wastes into larger bodies of water such as a large estuary or the Gulf of Mexico. Dilution of return flows, however, is not even now adequate in many areas, and, as the population expands, water which could be used for this purpose would be in still greater demand. The potentials offered in the future by desalinization of sea water —such a plant is now in operation at Freeport, Texas (Fig. 10)—may offer partial remedy.

*Figure 10. Desalinization plant at Freeport, Texas.*

The other two methods could be costly. Altering the chemical properties of the return flow by the various users would require different methods of treatment and the cost of some could well be prohibitive. Dispersion of wastes into large bodies of water such as the Gulf of Mexico or, if properly regulated, open waters of Galveston Bay, might offer a solution. But the transport of wastes over a considerable distance would be prohibitive to all save large municipalities and industries or to those situated near these bodies of water. This method would, however, prevent the trapping of wastes in such limited areas as Clear Lake.

The maintenance of a suitable estuarine habitat is essential to the commercial and sport fisheries of Texas and the Gulf coast. Research must be continued and intensified in each of the estuaries in order to: (1) obtain a complete documentation of fishery resource values; (2) determine more exacting estimates of minimum natural fresh-water discharge requirements; (3) determine the most opportune time for release of fresh water should it not be available in sufficient quantities throughout the year; (4) determine if return flows, quality permitting, could partially replace direct tributary discharge; and (5) establish criteria to assist in developing plans to prevent losses in estuaries from pesticides and other pollutants. It is our hope that large water-development projects will become truly multi-purpose so as to consider all major national resources.

## ACKNOWLEDGMENTS

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# RED WATER BLOOM OF A DINOFLAGELLATE IN HILLSBOROUGH BAY, FLORIDA

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# Red Water Bloom of a Dinoflagellate in Hillsborough Bay, Florida

WATERS of Tampa Bay, Florida, are regularly sampled for plankton in connexion with studies of the Florida red-tide organism (*Gymnodinium breve*, Davis) and estuarine ecology. On May 5, 1964, various division stages and chain formations of an armoured dinoflagellate, *Ceratium furca* (Ehrenberg), were detected in the surface waters of Hillsborough Bay, an upper arm of Tampa Bay. The water samples were tinted brown and contained an average count of $2{\cdot}294 \times 10^5$ cells of *C. furca* per litre. Two weeks later, during an aerial survey of Tampa Bay, two staff biologists noticed patches of blood-red water in the upper portion of Hillsborough Bay. On May 25, during a special cruise in Hillsborough Bay, water in the entire upper portion of the Bay was discoloured with brownish and reddish patches. The most intense discoloration was noticed in areas protected from the wind. No mortality of fish or any other organism was observed in the field. Blue crabs, *Callinectes sapidus* Rathbun, and scaled sardines, *Harengula pensacolae* Goode and Bean, were actively swimming through the patches of blood-red water without showing ill effects.

All organisms were enumerated in the living state by counting techniques previously reported[1]. Before counting the organisms, two-litre Erlenmeyer flasks containing the samples were placed under a fluorescent light in the laboratory to concentrate phototropic organisms. *C. furca* concentrated in the meniscus of the flasks 15–30 min after exposure to the light, giving it a brownish-red tint. In red water samples, *C. furca* was noted in very high concentrations, probably the highest on record for this dinoflagellate. The density of cells varied from $2{\cdot}24 \times 10^6$ to $14{\cdot}29 \times 10^6$ cells per litre.

Microflagellates, 4–7$\mu$ in diameter, were also abundantly represented in the water samples. Furthermore, they were numerous in non-discoloured water from the same general area, suggesting that they played no part in the red discoloration. Some samples containing *C. furca* and these flagellates also yielded very small numbers of *Polykrikos* sp., *Prorocentrum micans* Ehrenberg, *Gonyaulax* sp., *Coscinodiscus centralis* Ehrenberg, *Rhizosolenia setigera* Brightwell, *Biddulphia sinensis* Greville, and veliger-type larvae. These organisms were rare and did not contribute significantly to the intense colour.

A third cruise was made to the area on June 1. At this time the discoloured water contained blooms of *Sceletonema costatum* (Greville) Cleve in addition to blooms of

*C. furca*. The discoloration was much less pronounced than in blooms consisting principally of *C. furca*. Patches of blood-red water were absent, but the water retained a reddish hue. Concentrations of *C. furca* varied from $3{\cdot}1 \times 10^5$ to $5{\cdot}57 \times 10^6$ cells per litre. The cell density of *S. costatum* ranged from $4{\cdot}9 \times 10^5$ to $1{\cdot}45 \times 10^6$ cell chains per litre. By June 12, discoloured water had disappeared from the area, and only very low concentrations of *C. furca* and *S. costatum* were present in the samples. The area was inspected again on June 22, and no discoloration was noted.

A laboratory experiment was conducted to test light absorbency as an indicator of the degree of water coloration by *C. furca* cells. Aliquots from a bloom containing $14{\cdot}3 \times 10^6$ cells per litre were serially diluted from 100 per cent to 5 per cent by volume in 5 per cent increments. The diluted aliquots were then shaken slightly to distribute the organisms. Spectrophotometer cells of one-centimetre path length were filled with the dilution, and the absorbency measured at 400 mμ. The pattern of the observed absorbencies agreed with the volume dilutions. A maximum of 0·180 was noted for the 100 per cent volume and 0·018 for the 10 per cent volume.

To test the toxicity of a *Ceratium furca* bloom on fish, several specimens of *Lagodon rhomboides* (Linnaeus), 95–112 mm (FL), *Paralichthys albigutta* Jordan and Gilbert, 104–5 mm (FL), and a specimen of *Chaetodipterus faber* (Broussonet), 125 mm (FL), were selected. These fish were kept for 36 h in an aerated 15-gal. tank containing high concentrations ($14{\cdot}29 \times 10^6$ cells per litre) of this dinoflagellate. The fish remained active and behaved normally throughout the experiment. After the experiment, all *C. furca* were deliberately killed. As the dead dinoflagellates settled to the bottom of the tank, the water regained its normal transparency.

The observations presented indicate that unusually dense concentrations of *C. furca* were responsible for the blood-red discoloration, and that there was no toxic effect on fish. The possibility that discoloration was also caused by the bloom of *S. costatum* cells is remote since the samples taken on May 25 from blood-red patches of water contained only blooms of *C. furca*. In water samples from areas of *C. furca* and *S. costatum* blooms, the intensity of discoloration was less than in water containing only *C. furca* blooms. *S. costatum* is one of the most abundant diatoms in Hillsborough Bay. Each year, blooms are observed throughout the winter and into the spring months. No water discoloration has been associated with *S. costatum* blooms.

The association of *C. furca* blooms and water discoloration in Florida is reported here for the first time. One of the more frequently observed sea-water discolorations along the south-western coast of Florida is commonly known as 'red tide'. This is a natural fish-killing phenomenon and is always associated with discoloured water containing dense populations of *Gymnodinium breve*, a naked dinoflagellate[2]. The discoloration of water during the outbreaks of the Florida red tide may vary between brown, red and green. Another discoloration of biological origin in Tampa Bay and off the west coast of Florida was reported by Hutton[3]. He did not mention the colour of the water, which he associated with blooms of *Gymnodinium splendens* Lebour. He described the discoloration in offshore waters as streaks of reddish-brown water, approximately one mile in width. The water contained $3 \cdot 5 \times 10^4$ specimens of *Acartia tonsa* Dana per litre. *Labidocera aestiva* was also present in Hutton's samples but in smaller numbers than *A. tonsa*. Hutton observed no damage of fish in connexion with the blooms of *G. splendus*, *A. tonsa* or *L. aestiva*.

A blue-green alga, *Skujaella* (*Trichodesmium*) *thiebauti* De Toni, is associated with brownish discoloration in coastal waters of south-western Florida. Fish kills caused by this alga have not been reported from the area.

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[1] Dragovich, A., U.S. Fish and Wildlife Service, Special Scientific Report—Fisheries, 372 (1961).

[2] Dragovich, A., and May, B. Z., U.S. Fish and Wildlife Service, *Fishery Bulletin*, **205**, 62 (1962).

[3] Hutton, R. F., *Quart. J. Fla. Acad. Sci.*, **23**, 2 (1960).

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# Food of Lake Trout in Lake Superior

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## ABSTRACT

Stomachs were examined from 1,492 lake trout and 83 siscowets collected from Lake Superior. Data are given on the food of lake trout of legal size (17 inches or longer) by year, season, and depth of water, and on the relation between food and size among smaller lake trout.

Fish contributed 96.7 to 99.9 per cent of the total volume of food in the annual samples. Ciscoes (*Coregonus* spp.) were most common (52.2 to 87.5 per cent of the volume) in 1950 to 1953 and American smelt ranked first (65.6 per cent of the volume) in 1963. Cottids were in 8.9 to 12.3 per cent of the stomachs in 1950 to 1953 but in only 4.3 per cent in 1963. Insects ranked second to fish in occurrence (9.6 per cent for the combined samples) and crustaceans followed at 3.9 per cent.

The greatest seasonal changes in the food of lake trout were among fish caught at 35 fathoms and shallower. The occurrence of *Coregonus* increased from 34.6 per cent in February–March to 71.1 per cent in October–December. Smelt were in 76.9 per cent of the stomachs in February–March but in only 2.2 per cent in October–December. Cottids, *Mysis relicta*, and insects were most common in the July–September collections.

Lake trout taken at depths greater than 35 fathoms had eaten a higher percentage of Cottidae and *Coregonus* than had those captured in shallower water. Smelt, ninespine sticklebacks, *Mysis*, and insects were more frequent in stomachs of lake trout from less than 35 fathoms.

Crustaceans comprised more than 70 per cent of the total volume of food for 4.0- to 7.9-inch lake trout but their importance decreased as the lake trout grew larger. *Pontoporeia affinis* was the most common in the stomachs of 4.0- to 6.9-inch lake trout and *Mysis* held first rank at 7.0 to 12.9 inches. Ostracods were important only to 4.0- to 4.9-inch lake trout. As the lake trout became larger, the importance of fish grew from 4.4-per cent occurrence at 5.0 to 5.9 inches to 93.9 per cent at 16.0 to 16.9 inches. Smelt were most commonly eaten by undersize (less than 17 inches) lake trout.

## INTRODUCTION

The lake trout (*Salvelinus namaycush*) has been of extreme interest to investigators of the Great Lakes since the sea lamprey (*Petromyzon marinus*) spread to the upper lakes in the mid-1930's. After the collapse of the fisheries for lake trout in Lake Huron and Lake Michigan, special attention was given to Lake Superior, the last of the upper Great Lakes in which populations of native lake trout still exist.

The earlier work on the life history of the lake trout in Lake Superior included the collection of data and materials on the food of the species. Collections in 1950 to 1953 were made from commercial landings by the staff of the U. S. Fish and Wildlife Service (Bureau of Commercial Fisheries) Biological Station at Marquette, Michigan. Later materials were collected in 1963 from commercial landings and in 1958 to 1963 by the research vessel *Siscowet* at Ashland, Wisconsin. These materials form the basis for this report.

A number of papers have been published on the food of lake trout (reviewed by Van Oosten and Deason, 1938), but the only ones on the Great Lakes stocks are for Lake Ontario (Dymond, 1928), Lake Michigan (Van Oosten and Deason, 1938), and Lake Superior (Eschmeyer, 1956). Eschmeyer's study was confined to the food of lake trout during their first 3 years of life. The present paper expands the knowledge to larger lake trout of Lake Superior.

## MATERIALS AND METHODS

Details on collections of 1,492 lake trout (*Salvelinus namaycush namaycush*) and 83 siscowets (*S. namaycush siscowet*) sampled from commercial landings at various locations and seasons in 1950 to 1953 and 1963 appear

TABLE 1.—*Number of stomachs examined from Lake Superior lake trout and siscowets taken by commercial gear, 1950 to 1953 and 1963*

| Date | Port | Depth (fathoms) | Number examined | Number containing food | | Total length[1] (inches) | |
|---|---|---|---|---|---|---|---|
| | | | | Lake trout | Siscowet | Average | Range |
| 1950 | | | | | | | |
| July | Marquette | 60–80 | 36 | 14 | 12 | 21.2 | 15.1–29.9 |
| August | Marquette | 10–90 | 208 | 124 | 27 | 18.3 | 10.0–30.9 |
| September | Marquette | 10–22 | 231 | 147 | — | 22.8 | 12.0–33.9 |
| September | Munising | 12–24 | 62 | 30 | — | 29.3 | 16.0–37.9 |
| September | Grand Marais | 16–30 | 36 | 20 | — | 18.1 | 12.0–34.9 |
| September | Ontonagon | 10–20 | 80 | 34 | — | 24.6 | 11.0–37.9 |
| September | Copper Harbor | 18–35 | 32 | 22 | — | 16.1 | 10.0–28.9 |
| October | Bete Grise | 10 | 34 | 15 | — | 27.7 | 20.0–32.9 |
| October | Marquette | 11–19 | 64 | 28 | — | 27.6 | 15.0–36.9 |
| November | Marquette | 11–70 | 113 | 41 | 5 | 24.7 | 18.0–40.9 |
| December | Marquette | 30–80 | [2]— | 64 | 20 | 21.2 | 14.0–33.9 |
| 1951 | | | | | | | |
| April | Marquette | 28–33 | 47 | 41 | — | 20.4 | 9.0–29.9 |
| May | Marquette | 28–35 | [2]— | 21 | — | 24.5 | 15.0–42.9 |
| June | Marquette | 18–35 | 43 | 27 | — | 21.2 | 11.0–33.9 |
| July | Cornucopia | 10 | 49 | 42 | — | 19.2 | 16.0–28.9 |
| August | Marquette | 12–25 | 43 | 29 | — | 25.3 | 16.0–35.9 |
| August | Bete Grise | 10 | 41 | 6 | — | 24.8 | 17.0–31.9 |
| October | Marquette | 12–18 | 20 | 4 | — | 25.3 | 16.0–31.9 |
| 1952 | | | | | | | |
| June | Cornucopia | 10 | [2]— | 52 | — | 19.6 | 16.0–28.9 |
| June | Marquette | 30 | [2]— | 17 | — | 20.2 | 16.0–28.9 |
| August | Marquette | 10–15 | 57 | 30 | — | 21.4 | 15.0–31.9 |
| 1953 | | | | | | | |
| February | Marquette | 34–70 | 118 | 67 | 13 | 20.0 | 7.0–28.9 |
| March | Marquette | 26–48 | 44 | 32 | — | 20.0 | 12.0–29.9 |
| April | Marquette | 17–72 | 64 | 36 | 6 | 21.2 | 12.0–28.9 |
| May | Marquette | 22–25 | 27 | 20 | — | 23.2 | 19.0–37.9 |
| June | Marquette | 20–23 | 96 | 32 | — | 17.4 | 12.0–28.9 |
| July | Marquette | [3]— | 14 | 8 | — | 25.5 | 22.0–29.9 |
| 1963 | | | | | | | |
| August | Bayfield | 25 | 38 | 38 | — | 21.6 | 8.0–26.0 |
| September | Marquette | 12–18 | 17 | 15 | — | 21.0 | 8.4–29.4 |
| Total or average | | — | [2]— | 1,056 | 83 | 21.4 | 7.0–42.9 |

[1] Lake trout and siscowets combined.
[2] Unknown.
[3] Floating 2 fathoms below the surface in water 50 fathoms deep.

in Table 1; records of catches of the Bureau's research vessel *Siscowet* in 1958 to 1963 are in Table 2. All sampling points can be located in Figure 1. The lengths of the fish from commercial gear ranged from 7.0 to 42.9 inches (average, 21.4). Most were captured in 4½- to 6-inch-mesh (extension measure) gill nets; a few were taken in 2½-inch-mesh gill nets, pound nets (50 to 70 feet deep, 4½- to 4¾-inch-mesh pot), and from set hooks (No. 6 hooks spaced 30 feet apart, usually baited with small lake herring, and suspended from a line floated about 2 fathoms below the surface). The other 436 stomachs came from lake trout captured in experimental gill nets (1- to 5-inch mesh) and bottom trawls (31-foot semiballoon, 2½-inch-mesh body, and ½-inch-mesh cod end) fished by the *Siscowet* in the Apostle Islands, in Keweenaw Bay, and at Isle Royale (Table 2). These fish were 4.0 to 16.7 inches long (average, 8.1).

Each stomach from commercially landed lake trout was wrapped in muslin, labeled (total length of the fish, location, gear, depth, and date of collection), and preserved in 10-per cent formalin. The empty stomachs (stomachs that seemed to be empty were opened to make certain of their condition) were not preserved but full data on the fish were recorded. Stomach contents were analyzed at the Bureau's Biological Laboratory in Ann Arbor, Michigan, or at Biological Stations at Marquette and Ashland.

Lake trout captured by the *Siscowet* were preserved whole and the collections were labeled according to date, location, gear, and depth of water. The stomachs were later removed from the preserved fish for examination. No adjustments were made for shrinkage in length of the fish due to preservation.

Quantitative determinations for food of the commercially landed lake trout in 1950 to

TABLE 2.—*Number of stomachs examined from Lake Superior lake trout collected by the M/V* Siscowet, *1958 to 1963*

| Date | Location | Depth (fathoms) | Number examined | Number containing food | Total length (inches) | |
|---|---|---|---|---|---|---|
| | | | | | Average | Range |
| 1958 | | | | | | |
| July | Apostle Islands | 10–12 | 2 | 2 | 9.2 | 8.7– 9.7 |
| August | Apostle Islands | 13 | 3 | 1 | 14.0 | — |
| 1959 | | | | | | |
| July | Apostle Islands | 15–27 | 3 | 1 | 5.2 | — |
| August | Apostle Islands | 19–26 | 13 | 13 | 6.4 | 4.9– 8.1 |
| 1960 | | | | | | |
| August | Isle Royale | 20–72 | 54 | 46 | 12.7 | 10.2–16.7 |
| 1961 | | | | | | |
| July | Apostle Islands | 15–19 | 10 | 9 | 5.5 | 4.3– 7.8 |
| August | Keweenaw Bay | 18–30 | 72 | 65 | 6.0 | 4.0– 8.7 |
| 1962 | | | | | | |
| May | Apostle Islands | 30 | 42 | 36 | 8.4 | 6.6–13.3 |
| June | Apostle Islands | 25 | 90 | 86 | 8.5 | 5.8–12.2 |
| September | Apostle Islands | 22 | 50 | 48 | 6.7 | 4.8– 9.0 |
| November | Apostle Islands | 20 | 36 | 31 | 7.5 | 5.1–12.4 |
| December | Apostle Islands | 19 | 27 | 25 | 7.5 | 5.7–10.8 |
| 1963 | | | | | | |
| February | Apostle Islands | 18–29 | 48 | 38 | 6.8 | 5.6–10.8 |
| March | Apostle Islands | 2–24 | 38 | 35 | 9.6 | 6.0–15.5 |
| Total or average | | | 488 | 436 | 8.1 | 4.0–16.7 |

1953 were made by wet weight to the nearest 0.1 gram with a triple-beam balance; all others were made by liquid displacement in a sedimentation tube graduated to 0.01 milliliter. Volume and weight were considered to be equivalent; i.e., 1 gram corresponds to 1 milliliter.

Some explanations are required to permit an instructive description of the food of Lake Superior lake trout from the records of Tables 3 to 5. Comparison of the food of lake trout and siscowets (not given here) revealed only minor differences, which probably represented sample variations rather than real differences in food. The data for lake trout and siscowets from commercial gear were accordingly combined for this study; the term "lake trout" includes siscowets. The *Siscowet* took only lake trout.

The extent to which the food had been digested affected the accuracy of identification. Many of the sculpins and ciscoes (*Coregonus* spp.) were originally identified to species in 1950 to 1953. *Cottus bairdi* and *C. cognatus* were troublesome to separate, however, and even fresh specimens of the ciscoes often are difficult to identify. Consequently, we believe that the pooling of all Cottidae (except the fourhorn sculpin, *Myoxocephalus quadricornis*, which was relatively easy to identify) and all the ciscoes offers the best measure of their importance as food of lake trout.[1] Obviously, the amount of unidentified food in the stomachs affected the percentages of volume and occurrence for individual items.

## ANNUAL DIFFERENCES IN FOOD OF LEGAL-SIZE LAKE TROUT, 1950 TO 1953 AND 1963

The food of legal-size[2] lake trout varied somewhat according to year, season of capture, and depth of water, but little with length of fish. The data were not adequate to show differences according to geographical location in the lake but they did not appear to be great. The data on the food of lake trout in each of the 5 years and for the combined samples (Table 3) provide both a record of annual

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[1] Species tentatively identified in the genus *Cottus* were *bairdi cognatus*, and *ricei*. The identified species of *Coregonus* were *artedi*, *hoyi*, *zenithicus*, and *reighardi*. Lake whitefish (*Coregonus clupeaformis*), round whitefish (*Prosopium cylindraceum*), and pygmy whitefish (*P. coulteri*) were not found in any stomach.

[2] The minimum legal size for lake trout is 17 inches, total length, in Wisconsin and 1½ pounds, round, or 1¼ pounds, dressed (approximately 17 inches), in Michigan. In this paper, 17 inches is considered the minimum legal size.

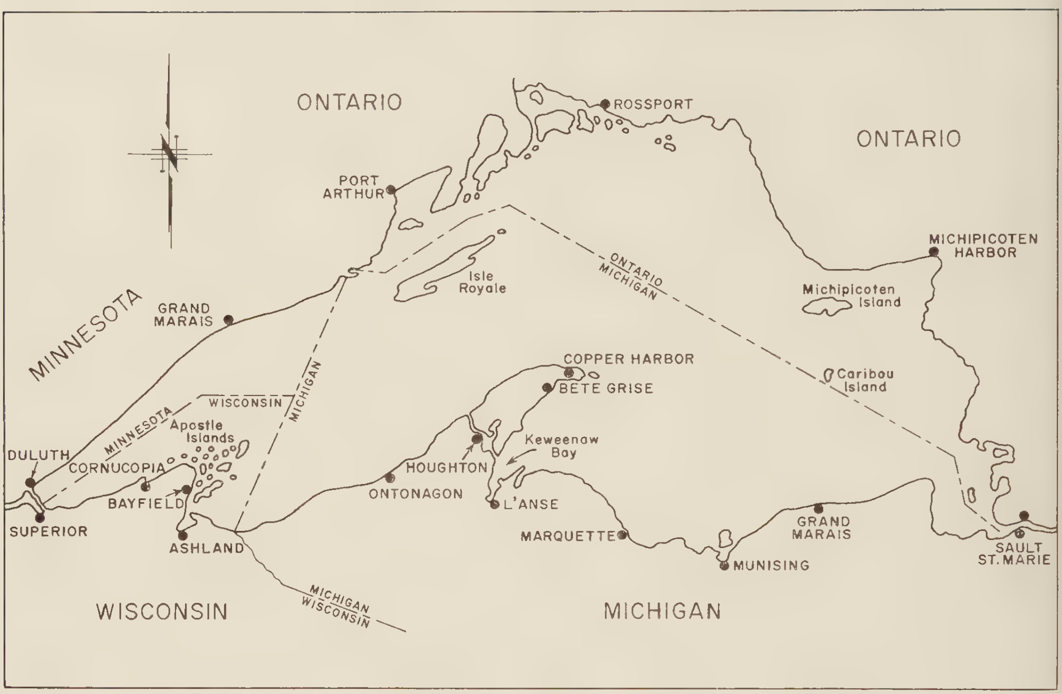
ONTARIO
ROSSPORT
ONTARIO
PORT ARTHUR
MICHIPICOTEN HARBOR
Isle Royale
ONTARIO
MICHIGAN
Michipicoten Island
MINNESOTA
GRAND MARAIS
COPPER HARBOR
BETE GRISE
Caribou Island
WISCONSIN
MICHIGAN
MINNESOTA
Apostle Islands
Keweenaw Bay
DULUTH
CORNUCOPIA
HOUGHTON
ONTONAGON
L'ANSE
BAYFIELD
SUPERIOR
ASHLAND
MARQUETTE
GRAND MARAIS
MUNISING
SAULT ST. MARIE
WISCONSIN
MICHIGAN
WISCONSIN
MICHIGAN

Fig. 1.—Lake Superior.

differences and a general summary of the feeding habits of Lake Superior lake trout.

Fish were by far the most important food of legal-size lake trout. They were in 87.0 to 100.0 per cent of the stomachs in the annual samples and contributed 96.7 to 99.9 per cent of the total volume. The values for the combined samples in the 5 years of collections were 92.3-per cent occurrence and 98.1 per cent of the volume. Ciscoes were the most common in 1950 to 1953 when they contributed 52.2 to 87.5 per cent of the volume. In 1963, however, the American smelt (*Osmerus mordax*) ranked first and the representation of *Coregonus* was only 8.1 per cent of the volume and 6.4-per cent occurrence. The contribution of smelt climbed from 1.7 per cent of the volume of food in 1950 to 42.1 per cent in 1952. The value decreased to 27.3 per cent in 1953 but reached 65.6 per cent in 1963. Bailey (1964) reported that the first significant landings of smelt in Lake Superior were made in 1952. The annual commercial take increased to nearly 1 million pounds in 1960.

Cottids were in 8.9 to 12.3 per cent of the stomachs in 1950 to 1953 but in only 4.3 per cent in 1963; the fourhorn sculpin was the most common.

The importance of other species of fish as food of legal-size lake trout was small. Ninespine sticklebacks (*Pungitius pungitius*) were in each year's samples but their average occurrence was only 3.8 per cent. Trout-perch (*Percopsis omiscomaycus*) and burbot (*Lota lota*) were found only in the 1951 samples, and occasional small lake trout were in the stomachs collected in 1950 and 1953.

Crustaceans were in only 3.9 per cent of the stomachs and composed 0.4 per cent of the total volume. *Mysis* was most frequent in 1950 to 1953 but was absent in 1963. *Pontoporeia* was in 6.4 per cent of the lake trout stomachs in 1963.

Insects ranked second to fish in occurrence (9.6 per cent for the combined samples) but made up only 1.3 per cent of the volume. Formicidae, Lepidoptera, and Coleoptera were the most common.

Dymond (1928) reported that lake trout from commercial gill nets in Lake Ontario ate

TABLE 3.—*Percentage of occurrence and (in parentheses) percentage of total volume of food in stomachs of legal-size lake trout, 1950 to 1953 and 1963*

[0.0 indicates less than 0.05]

| Item | 1950 | 1951 | 1952 | 1953 | 1963 | Combined samples |
|---|---|---|---|---|---|---|
| Number of stomachs | 486 | 156 | 95 | 187 | 47 | 971 |
| Food | | | | | | |
| Fish (total) | 87.0 | 90.4 | 87.4 | 96.8 | 100.0 | 92.3 |
| | (98.2) | (96.8) | (96.7) | (99.5) | (99.9) | (98.1) |
| *Coregonus*[1] | 59.3 | 52.6 | 49.5 | 56.1 | 6.4 | 44.8 |
| | (87.5) | (61.1) | (52.2) | (67.7) | ( 8.1) | (55.3) |
| American smelt | 3.1 | 30.8 | 36.8 | 32.6 | 68.1 | 34.3 |
| | ( 1.7) | (21.0) | (42.1) | (27.3) | (65.6) | (31.5) |
| Cottidae[1] | 10.7 | 8.9 | — | 12.3 | 4.3 | 7.2 |
| | ( 2.0) | ( 0.8) | — | ( 1.7) | ( 1.0) | ( 1.1) |
| *Cottus* spp.[2] | 2.9 | 3.8 | — | 0.5 | — | 1.4 |
| | ( 0.6) | ( 0.4) | — | ( 0.0) | — | ( 0.2) |
| Fourhorn sculpin | 3.1 | 1.9 | — | 7.5 | — | 2.5 |
| | ( 0.8) | ( 0.1) | — | ( 0.6) | — | ( 0.3) |
| Ninespine stickleback | 5.3 | 6.4 | 4.3 | 1.1 | 2.1 | 3.8 |
| | ( 0.8) | ( 1.3) | ( 0.3) | ( 0.0) | ( 0.1) | ( 0.5) |
| Trout-perch | — | 3.2 | — | — | — | 0.6 |
| | — | ( 0.3) | — | — | — | ( 0.1) |
| Burbot | — | 2.6 | — | — | — | 0.5 |
| | — | (11.2) | — | — | — | ( 2.2) |
| Lake trout | 0.2 | — | — | 0.5 | — | 0.1 |
| | ( 0.3) | — | — | ( 0.3) | — | ( 0.1) |
| Unidentified fish | 30.7 | 10.3 | 14.7 | 18.2 | 66.0 | 28.0 |
| | ( 5.9) | ( 1.1) | ( 2.1) | ( 2.5) | (25.1) | ( 7.3) |
| Crustaceans (total) | 6.6 | 3.8 | 1.1 | 1.6 | 6.4 | 3.9 |
| | ( 1.2) | ( 0.5) | ( 0.3) | ( 0.1) | ( 0.1) | ( 0.4) |
| *Mysis relicta* | 6.6 | 3.2 | 1.1 | 1.6 | — | 2.5 |
| | ( 1.2) | ( 0.5) | ( 0.3) | ( 0.1) | — | ( 0.4) |
| *Pontoporeia affinis* | — | 0.6 | — | — | 6.4 | 1.4 |
| | — | ( 0.0) | — | — | ( 0.1) | ( 0.0) |
| Insects (total) | 7.0 | 16.0 | 18.9 | 5.9 | — | 9.6 |
| | ( 0.3) | ( 2.7) | ( 3.0) | ( 0.4) | — | ( 1.3) |
| Orthoptera | — | 1.9 | — | 0.5 | — | 0.5 |
| | — | ( 0.0) | — | ( 0.0) | — | ( 0.0) |
| Odonata | 0.8 | 6.4 | 3.2 | 0.5 | — | 2.2 |
| | ( 0.0) | ( 0.8) | ( 0.0) | ( 0.0) | — | ( 0.2) |
| Hemiptera | 0.2 | — | 2.1 | 0.5 | — | 0.6 |
| | ( 0.0) | — | ( 0.0) | ( 0.0) | — | ( 0.0) |
| Coleoptera | 0.6 | 3.8 | 9.5 | 0.5 | — | 2.9 |
| | ( 0.0) | ( 0.0) | ( 0.2) | ( 0.0) | — | ( 0.0) |
| Lepidoptera | 1.2 | 9.0 | 9.5 | 0.5 | — | 4.0 |
| | ( 0.0) | ( 1.6) | ( 1.6) | ( 0.1) | — | ( 0.7) |
| Diptera | 1.6 | 1.9 | 7.4 | — | — | 2.2 |
| | ( 0.2) | ( 0.0) | ( 0.0) | — | — | ( 0.0) |
| Formicidae | 2.1 | 6.4 | 13.7 | 2.7 | — | 5.0 |
| | ( 0.0) | ( 0.3) | ( 1.2) | ( 0.3) | — | ( 0.4) |
| Unidentified insects | 1.0 | — | — | — | — | 0.0 |
| | ( 0.1) | — | — | — | — | ( 0.1) |

[1] Includes all individuals of this group.
[2] Includes individuals tentatively identified as mottled, slimy, and spoonhead sculpin.

mostly alewives. *Coregonus* ranked second, followed by Cottidae.

### FOOD OF LEGAL-SIZE LAKE TROUT BY SEASONS AND DEPTH OF WATER

The 1950 to 1953 Marquette samples were chosen for the study of changes in the food of lake trout with season and depth because they represented a greater span of both seasons and depths than did samples from other locations. Although the food of lake trout, as earlier described, did vary somewhat from year to year (Table 3), the records for the individual samples revealed that changes by season and depth were consistent regardless of the year in which the samples were collected. Consequently, the annual samples could be combined for the study of seasonal and depth differences. Because the data were not adequate to show changes by small depth intervals, an arbitrary division was made between samples collected down to and below 35 fathoms. This separation seemed to fit best the general differences. Only major foods were considered in this study; the frequency of occurrence of less important foods was extremely small.

Seasonal differences in the food of lake trout were greatest in samples from depths of 35 fathoms or less (Table 4). The occurrence of *Coregonus* increased from 34.6 per cent in the February–March collections to 71.1 per cent in October–December; the percentage of the total volume increased from 48.3 to 98.1 over the same period. The importance of

TABLE 4.—*Percentage of occurrence and (in parentheses) percentage of volume of major foods in stomachs of legal-size lake trout according to season and depth, Marquette, 1950 to 1953*

[0.0 indicates less than 0.05]

| Food and depth | Season | | | |
|---|---|---|---|---|
| | Feb.–Mar. | Apr.–June | July–Sept. | Oct.–Dec. |
| *Coregonus* | | | | |
| Shallow[1] | 34.6 | 37.6 | 45.9 | 71.1 |
| | (48.3) | (55.2) | (76.3) | (98.1) |
| Deep[2] | 73.5 | 86.7 | 54.8 | 77.6 |
| | (94.8) | (96.9) | (94.2) | (98.8) |
| American smelt | | | | |
| Shallow | 76.9 | 46.5 | 9.4 | 2.2 |
| | (51.5) | (41.5) | (15.7) | ( 0.7) |
| Deep | 1.2 | 3.3 | — | — |
| | ( 1.1) | ( 2.3) | — | — |
| Cottidae | | | | |
| Shallow | 3.8 | 8.2 | 10.6 | 4.4 |
| | ( 0.0) | ( 0.6) | ( 2.1) | ( 0.1) |
| Deep | 31.3 | 13.3 | 25.8 | 12.1 |
| | ( 4.1) | ( 0.8) | ( 5.3) | ( 1.2) |
| Ninespine stickleback | | | | |
| Shallow | — | 4.7 | 7.6 | 8.9 |
| | — | ( 1.1) | ( 1.7) | ( 0.6) |
| Deep | — | — | 1.6 | 0.9 |
| | — | — | ( 0.2) | ( 0.0) |
| *Mysis relicta* | | | | |
| Shallow | 3.8 | 8.2 | 22.2 | 6.7 |
| | ( 0.2) | ( 0.6) | ( 3.5) | ( 0.2) |
| Deep | 3.6 | — | — | 1.9 |
| | ( 0.0) | — | — | ( 0.0) |
| Insects | | | | |
| Shallow | — | 5.9 | 11.9 | 6.7 |
| | — | ( 1.0) | ( 0.7) | ( 0.3) |
| Deep | — | — | 3.2 | — |
| | — | — | ( 0.3) | — |
| Number of stomachs | | | | |
| Shallow | 26 | 170 | 329 | 45 |
| Deep | 83 | 30 | 62 | 107 |

[1] 35 fathoms or less.

[2] More than 35 fathoms.

American smelt, on the other hand, was greatest in the February–March samples (76.9-per cent occurrence, 51.5 per cent of the volume) and decreased progressively to October–December (2.2-per cent occurrence and 0.7 per cent of the volume). The percentage of stomachs containing Cottidae increased from 3.8 per cent in February–March to 10.6 per cent in July–September, but dropped to 4.4 per cent in October–December. Ninespine sticklebacks were lacking in the February–March samples but were in 8.9 per cent of the stomachs collected in October–December. The importance of *Mysis* followed closely that of Cottidae; mysids were most frequent in the July–September collections and were less common in the February–March and October–December samples. Stomachs of lake trout collected in February–March contained no insects but the occurrence was 11.9 per cent in the fish of the July–September collections.

Seasonal differences were smaller in the samples from depths below 35 fathoms. Cottidae were most abundant in February–March and July–September, and *Coregonus* was most important (98.8 per cent of the volume) in the October–December samples. The records for other foods were too scanty to show seasonal changes.

The percentage of lake trout stomachs void of food (data not given in table) did not vary greatly from one season to the next. The average percentage of stomachs without food was 39.4 per cent (range, 46.2 per cent in October–December to 30.9 per cent in February–March).

Van Oosten and Deason (1938) reported that small lake trout (mostly under 16 inches long) from Lake Michigan appeared to feed less on Cottidae and more on *Coregonus* during the early summer, but no consistent seasonal variations were observed for other foods.

The principal difference in the food of lake trout caught at different depths was the higher percentage of stomachs which contained Cottidae and ciscoes among lake trout from the deeper water. Smelt, conversely, were by a wide margin more abundant in stomachs of fish from less than 35 fathoms. Ninespine sticklebacks, *Mysis*, and insects were less frequent in stomachs of lake trout from deep water than in those from shallow water.

Small lake trout captured in the deeper waters of Lake Michigan contained a high percentage of Cottidae but ciscoes appeared most frequently in the stomachs of lake trout caught in shallow water (Van Oosten and Deason, 1938). Ninespine sticklebacks were an important food only for lake trout captured in less than 50 fathoms in northern Lake Michigan.

### RELATION BETWEEN FOOD AND SIZE OF LAKE TROUT UNDER 17 INCHES LONG

The 1958 to 1963 *Siscowet* collections and the undersize lake trout collected from the commercial fishery in 1950 to 1953 and 1963 have been combined by 1-inch intervals for the study of food according to size of fish (Table 5). Although the food of small lake trout varied slightly with season (fish eggs,

TABLE 5.—*Percentage occurrence and (in parentheses) percentage volume of food in stomachs of undersize lake trout taken by commercial gear in 1950 to 1953 and 1963, and by the* Siscowet *in 1958 to 1963*

[0.0 indicates less than 0.05]

| Item | Total length (inches) | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 4.0–4.9 | 5.0–5.9 | 6.0–6.9 | 7.0–7.9 | 8.0–8.9 | 9.0–9.9 | 10.0–10.9 | 11.0–11.9 | 12.0–12.9 | 13.0–13.9 | 14.0–14.9 | 15.0–15.9 | 16.0–16.9 | Total |
| Number of stomachs | 9 | 68 | 102 | 82 | 63 | 36 | 33 | 23 | 41 | 44 | 34 | 36 | 33 | 604 |
| Food | | | | | | | | | | | | | | |
| Fish (total) | 22.2 | 4.4 | 11.8 | 15.9 | 28.6 | 25.0 | 51.5 | 43.5 | 51.2 | 61.4 | 67.6 | 80.6 | 93.9 | 42.9 |
| | (20.8) | ( 1.8) | (23.4) | (26.0) | (57.6) | (67.4) | (68.4) | (40.3) | (55.5) | (77.2) | (89.5) | (90.1) | (96.6) | (54.9) |
| *Coregonus*[1] | — | — | — | — | — | — | — | 4.3 | — | 4.5 | 20.6 | 5.6 | 18.2 | 4.1 |
| | — | — | — | — | — | — | — | ( 5.1) | — | (10.2) | (13.8) | ( 6.5) | (20.6) | ( 4.3) |
| American smelt | — | — | 1.9 | 3.7 | 6.4 | 5.6 | 3.0 | — | 4.9 | 9.1 | 5.9 | 19.4 | 33.3 | 7.2 |
| | — | — | ( 5.3) | (10.4) | (20.8) | (10.4) | (16.6) | — | ( 7.8) | (18.3) | (18.2) | (37.8) | (49.5) | (15.0) |
| Cottidae[1] | — | — | — | — | 4.8 | 13.9 | 3.0 | 8.7 | 4.9 | 22.7 | 20.6 | 19.4 | 24.2 | 9.4 |
| | — | — | — | — | ( 5.2) | (24.0) | ( 6.0) | ( 5.1) | ( 9.0) | (11.2) | (25.4) | (18.0) | ( 5.1) | ( 8.4) |
| Ninespine stickleback | — | — | — | — | — | — | — | 4.3 | — | 2.3 | 11.8 | 16.7 | 12.1 | 3.6 |
| | — | — | — | — | — | — | — | ( 3.2) | — | ( 3.5) | ( 8.8) | (12.1) | ( 5.4) | ( 2.5) |
| Trout-perch | — | — | — | — | 3.2 | — | — | — | — | — | — | — | — | 0.2 |
| | — | — | — | — | ( 6.5) | — | — | — | — | — | — | — | — | ( 0.5) |
| Cyprinidae | — | — | — | — | — | — | — | — | — | — | — | — | 3.0 | 0.2 |
| | — | — | — | — | — | — | — | — | — | — | — | — | ( 0.5) | ( 0.0) |
| Northern pike[2] | — | — | — | — | — | — | — | — | — | — | — | — | 3.0 | 0.2 |
| | — | — | — | — | — | — | — | — | — | — | — | — | ( 0.8) | ( 0.1) |
| Fish eggs | — | 1.5 | 5.9 | 9.8 | 6.4 | 2.8 | 9.1 | — | — | — | — | — | — | 2.7 |
| | — | ( 0.1) | (10.5) | ( 8.5) | (14.4) | (14.6) | (20.4) | — | — | — | — | — | — | ( 5.3) |
| Unidentified fish | 22.2 | 2.9 | 3.9 | 11.0 | 11.1 | 16.7 | 36.4 | 26.1 | 43.9 | 22.6 | 29.4 | 19.4 | 12.1 | 19.8 |
| | (20.8) | ( 1.7) | ( 7.6) | ( 7.1) | ( 9.8) | (18.4) | (25.4) | (26.9) | (38.7) | (34.1) | (23.3) | (16.1) | (14.7) | (18.8) |
| Crustaceans (total) | 77.8 | 98.5 | 88.2 | 89.0 | 74.6 | 80.6 | 78.6 | 78.3 | 53.7 | 43.2 | 44.1 | 27.8 | 15.2 | 65.4 |
| | (79.2) | (91.6) | (73.0) | (76.5) | (42.9) | (28.7) | (31.7) | (59.7) | (44.2) | (22.7) | (10.5) | ( 9.4) | ( 3.4) | (44.1) |
| Conchostraca | — | 2.9 | 2.9 | — | — | — | — | — | — | — | — | — | — | 0.4 |
| | — | ( 0.2) | ( 0.0) | — | — | — | — | — | — | — | — | — | — | ( 0.0) |
| Ostracoda | 22.2 | 8.8 | 2.9 | 2.4 | — | — | — | — | — | — | — | — | — | 2.8 |
| | (12.5) | ( 0.2) | ( 0.0) | ( 0.0) | — | — | — | — | — | — | — | — | — | ( 0.0) |
| *Mysis relicta* | 22.2 | 50.1 | 58.9 | 76.8 | 68.3 | 61.1 | 75.8 | 73.9 | 56.1 | 43.2 | 44.1 | 27.8 | 15.2 | 51.8 |
| | (12.5) | (27.3) | (33.6) | (44.6) | (29.5) | (25.4) | (25.6) | (59.1) | (44.2) | ( 22.7) | (10.5) | ( 9.4) | ( 3.4) | (26.7) |
| *Pontoporeia affinis* | 55.6 | 66.2 | 61.8 | 62.3 | 52.4 | 41.7 | 24.2 | 8.7 | 4.9 | — | — | — | — | 29.1 |
| | (54.2) | (63.9) | (39.4) | (31.9) | (13.4) | ( 3.3) | ( 6.1) | ( 0.6) | ( 0.0) | — | — | — | — | (16.4) |
| Insects (total) | 22.2 | 23.5 | 21.6 | 18.3 | 14.3 | 33.3 | 6.1 | 21.7 | 4.9 | 11.4 | 8.8 | 8.3 | — | 15.0 |
| | ( 0.0) | ( 6.4) | ( 1.7) | ( 0.2) | ( 0.2) | ( 3.9) | ( 0.0) | ( 0.0) | ( 0.1) | ( 0.1) | ( 0.0) | ( 0.0) | — | ( 1.0) |
| Coleoptera | — | — | 1.0 | 1.2 | — | 2.8 | 3.0 | — | — | 2.3 | — | — | — | 0.8 |
| | — | — | ( 0.1) | ( 0.1) | — | ( 0.1) | ( 0.0) | — | — | ( 0.0) | — | — | — | ( 0.0) |
| Diptera | 1.1 | 14.7 | 11.8 | 9.8 | 12.7 | 16.7 | — | — | — | — | — | — | — | 5.1 |
| | ( 0.0) | ( 5.4) | ( 0.4) | ( 0.0) | ( 0.2) | ( 0.3) | — | — | — | — | — | — | — | ( 0.5) |
| Formicidae | — | 1.5 | 1.0 | — | — | — | — | — | — | 6.8 | 8.8 | — | — | 1.4 |
| | — | ( 1.0) | ( 0.0) | — | — | — | — | — | — | ( 0.0) | ( 0.0) | — | — | ( 0.0) |
| Unidentified insects | 1.1 | 7.4 | 7.9 | 7.3 | 3.2 | 13.9 | 3.0 | 21.7 | 4.9 | 6.8 | — | 8.3 | — | 6.6 |
| | ( 0.0) | ( 0.0) | ( 1.2) | ( 0.1) | ( 0.0) | ( 3.5) | ( 0.0) | ( 0.0) | ( 0.1) | ( 0.1) | — | ( 0.0) | — | ( 0.5) |
| Pelecypoda | — | 2.9 | 4.9 | 14.6 | 6.4 | 5.6 | — | — | 2.4 | — | — | — | — | 2.8 |
| | — | ( 0.2) | ( 0.2) | ( 0.1) | ( 0.2) | ( 0.0) | — | — | ( 0.2) | — | — | — | — | ( 0.0) |

[1] Includes all individuals in this group.

[2] *Esox lucius.*

for example, were found only in the late fall and early spring; insects were most common in midsummer and fall), the foods eaten were sufficiently similar to justify the combination of the data for all seasons. Combination of samples for different years and localities was also justifiable. Division of samples by depths of capture was unnecessary; nearly all of the fish were caught at depths less than 35 fathoms.

Crustaceans were present in more than 50 per cent of the stomachs of lake trout 4.0 to 12.9 inches long. They comprised more than 70 per cent of the total volume of food for 4.0- to 7.9-inch lake trout. As the lake trout grew larger, the importance of crustaceans declined—they accounted for only 3.4 per cent of the volume at 16.0 to 16.9 inches.

The amphipod *Pontoporeia* occurred in 66.2 per cent of the stomachs (63.9 per cent of the total volume) of 5.0- to 5.9-inch lake trout but its importance declined to nil when the lake trout reached 13 inches. *Mysis*, although less important than *Pontoporeia* to the smallest lake trout, gained first rank in percentage occurrence at 7.0 to 7.9 inches and held this position until the fish reached 13 inches. *Mysis* ranked first in volume of food for only the 7.0- to 7.9-inch and 11.0- to 11.9-inch groups. Ostracods were important only to the 4.0- to 4.9-inch lake trout. They were not eaten by fish longer than 7.9 inches.

Although Crustacea were the principal food of the smaller lake trout, fish contributed significantly to all the size groups. Among the 1-inch groupings represented by 10 or more lake trout, the percentage of stomachs containing fish climbed from 4.4 per cent at 5.0 to 5.9 inches to 93.9 per cent at 16.0 to 16.9 inches. Fish made up more than 50 per cent of the total volume of food for all lake trout longer than 8 inches (exception at 11.0 to 11.9 inches). The smallest lake trout that had eaten American smelt were at 6.0 to 6.9 inches. Cottidae entered the diet when the lake trout were 8.0 to 8.9 inches long, and *Coregonus* and ninespine sticklebacks appeared first at 11.0 to 11.9 inches. By the time the lake trout reached 16 inches, *Coregonus* and smelt contributed most to the volume of food and the importance of Cottidae and ninespine sticklebacks had decreased.

Fish eggs contributed significantly to the food of lake trout 5.0 to 10.9 inches long. The eggs were tentatively identified as those of *Coregonus*.

Insects appeared regularly in the stomachs of small lake trout (maximum occurrence, 33.3 per cent for the 9.0- to 9.9-inch group) but their contribution to the total volume never exceeded 6.4 per cent (at 5.0 to 5.9 inches). The smallest lake trout (4.0 to 9.9 inches) appeared to feed more extensively on insects than did the lake trout longer than 10 inches. The insects, in rank of importance, were Diptera, Formicidae, and Coleoptera.

Pelecypoda were present in some stomachs of the smaller lake trout but were unimportant in the total volume of food (never more than 0.2 per cent).

Eschmeyer (1956) determined that crustaceans were the most important food of 0- to II-group lake trout (1.1 to 8.9 inches long), but *Mysis* far outranked *Pontoporeia.* Fish were in 9 per cent of the stomachs and comprised about 13 per cent of the total volume of food. Van Oosten and Deason (1938) reported that no Lake Michigan lake trout longer than 18 inches had eaten invertebrates. Lake trout less than 15 inches long had consumed largely Cottidae and invertebrates; those larger than 15 inches had eaten Cottidae and *Coregonus.* Smelt were not firmly established in Lake Michigan when their samples were collected in 1930 to 1932; few were found in the stomachs of lake trout.

## LITERATURE CITED

BAILEY, MERRYLL M. 1964. Age, growth, maturity, and sex composition of the American smelt, *Osmerus mordax* (Mitchill), of western Lake Superior. Trans. Amer. Fish. Soc. 93: 382–395.

DYMOND, JOHN R. 1928. Some factors affecting the production of lake trout (*Cristivomer namaycush*) in Lake Ontario. Univ. Toronto Studies, Biol. Ser., Publ. Ontario Fish. Res. Lab. No. 33 (1928): 29–41.

ESCHMEYER, PAUL H. 1956. The early life history of the lake trout in Lake Superior. Mich. Dept. Cons. Inst. Fish. Res., Misc. Publ. No. 10, 31 pp.

VAN OOSTEN, JOHN, AND HILARY J. DEASON. 1938. The food of the lake trout (*Cristivomer namaycush namaycush*) and of the lawyer (*Lota maculosa*) of Lake Michigan. Trans. Amer. Fish. Soc. 67 (1937): 155–177.

# BIOGEOCHEMICAL CYCLING OF RADIONUCLIDES IN THE ESTUARINE ENVIRONMENT

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Estuaries are fertile breeding grounds for many organisms, but, unfortunately, they are the first marine areas to receive wastes from land-based nuclear reactors. Radioactive elements contained in this waste will enter into the biogeochemical cycles that are constantly in operation within the estuary. Because radioactivity can move through food webs of the estuary and be concentrated in seafood organisms, it is necessary to know the pathways taken by radioactive isotopes in estuarine environments. In addition to the radiological health aspects, data obtained on the cycling of radionuclides also can be especially useful in the management of estuarine areas to produce larger commercial and sport fishery yields. Such information as optimum nutrient levels, organisms used as food and the order of preference for these organisms, can be obtained by observing the movement of radioisotopes through selected marine environments. The movement or cycling of radioactivity can be observed *in situ* in the estuary by frequent sampling and the use of sensitive detecting equipment. However, because of the potential health hazard that radioactivity represents to man, it would be helpful to have such information before an estuary becomes polluted. Thus, experiments must be designed so that the movement of radioactivity in a marine community can be followed under controlled conditions.

The cycling of radionuclides through the components of a marine community can be followed in the laboratory. Valuable information can be obtained in the laboratory through the use of marine communities maintained in large volumes (100 or more gallons) of sea water even though it is not possible to duplicate the multiplicity and interactions of the many factors that influence the movement of elements in the natural environment. Recently, a more refined method has been employed in which the community is placed in a flowing sea water system where the concentration of metabolites is not allowed to build up in the water. This "community" approach, which utilizes large volumes of sea water, is more representative of conditions in an estuary than are the classical single species laboratory experiments where individual organisms are maintained in small volumes of water.

Radioactive materials introduced into the saline waters of an estuary can (1) remain in solution or form precipitates, (2) be scavenged by suspended material or settle to bottom sediment, or (3) be accumulated by plants or animals. Thus, the estuarine environment contains three components: water, sediments, and biota. A schematic illustration of possible pathways of radioisotopes introduced into an estuary is presented in Figure 1. Radioactive isotopes may be introduced as particles or in solution. Those isotopes that occur as particles may dissolve, while those that occur as dissolved substances may be sorbed onto particulate matter in the water, may be precipitated to form colloids or larger particles, or may remain as ions. Both particulate and dissolved substances can enter into biogeochemical cycles of the estuary. Sediments can accumulate radioisotopes from the water through an exchange process with stable isotopes of the element already in the sediment, or can be sorbed onto particle surfaces by an irreversible chemical reaction and not be readily available for exchange. Animals can accumulate radioactivity from the ingestion of food or sediment particles that have become radioactive, by absorption to their surfaces, or by absorption from the surrounding medium. Animals can obtain

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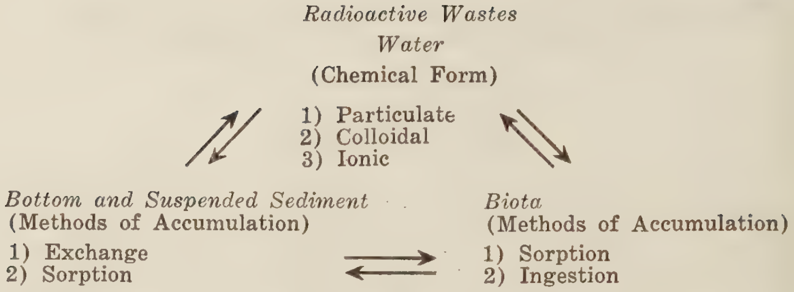

Figure 1. Cycling of radioactive waste in an estuary.

radioactivity from all three sources simultaneously or from each source at a time.

The cycling of two radioactive isotopes, zinc-65 and gold-199, through selected marine environments will be discussed. Zinc-65 was followed in a flowing sea water system maintained in the laboratory while the movement of gold-199 was observed in experiments conducted in the laboratory and in the natural environment.

## MOVEMENT OF ZINC-65 THROUGH A MARINE COMMUNITY

The cycling of radioactive zinc in a marine community maintained in flowing sea water was observed in a laboratory experiment. Zinc was chosen for this experiment because of its presence as a trace metal in marine organisms, especially shellfish, and because it is often present as an induced radioisotope, zinc-65, in many reactor wastes. To gain a more thorough understanding of the movement of radioactive zinc in an estuary, the water, sediments, and biota were analyzed for stable zinc as well as radioactive zinc. A knowledge of both stable and radioactive zinc present in the system permitted calculation of the specific activity (the ratio of radioactive zinc to total zinc) of each component. This ratio is important when considering the maximum amounts of radioactivity to which marine organisms can safely be exposed in relation to their use as seafood by man.

### Methods and Materials

A marine community which consisted of five fish *(Fundulus heteroclitus)*, five crabs *(Panopeus herbstii)*, five oysters *(Crassostrea virginica)*, five clams *(Mercenaria mercenaria)*, and five sediment samples of montmorillonite clay was placed in a fiberglass tank containing 200 liters of cotton-filtered sea water. An additional 5,600 liters were collected, cotton-filtered, and stored in fiberglass tanks. One hundred and fifty-seven microcuries of carrier-free zinc-65 were added and dispersed through the water in the holding tanks. This water was metered into the tank containing the community at a rate of 12 liters per hour. The animals and sediments were removed from the tank periodically, were measured for radioactivity, then returned to the tank. Water samples were also taken for analysis of stable zinc. Three individuals of each species and three sediment samples were removed from the tank on the 21st day and sacrificed for zinc determinations. The remaining oysters, clams, and sediment were left in a tank of flowing nonactive sea water so that the rate of loss of zinc-65 could be observed.

The zinc content of water, sediment, and organisms was determined by a colorimetric chemical technique. Animals to be analyzed were ashed in a muffle furnace, the ash taken to dryness in $HNO_3$ and the residues taken up in deionized water. The sample was then extracted for two minutes following the method of Vallee and Gibson (1948). The amount of zinc present was determined by comparing the amount of the zinc dithizonate formed in the extraction with that of standard solutions. Sediment extracts were first ion-exchanged through Dowex-1, an ion exchange resin, utilizing the procedure of Kraus and Moore

(1953). Water samples were analyzed by essentially the same procedures described by Grant (1962).

## Results and Discussion

The level of radioactive zinc in the water dropped from six to five counts per minute per gram during the course of the experiment. Chemical analysis showed that the stable zinc increased from 10.7 to 22.0 micrograms per liter of water. This increase presumably was due to the cycling of zinc from the organisms and sediment to the water. Evidently the water flow rate of 12 liters per hour was rapid enough to maintain 83 percent of the initial level of zinc-65, but not rapid enough to carry away the increase in stable zinc. The result of this increase in stable zinc and slight loss of zinc-65 was a decrease in the specific activity of the water. Such a decrease tends to slow the rate of transfer of zinc-65 from the water to the sediment and biota.

The accumulation of zinc-65 by sediments in the flowing sea water system is shown in Figure 2. There is an indication that the radioactive content of the sediment was approaching that of the water on the 21st day. This experimental environment contained only 60 grams of sediments that were maintained as a compact substrate. If the same level of radioactivity were reached by sediments in the natural environment where the entire bottom is covered with sediments, a large portion of the zinc-65 no doubt would be found in the sediments. After a study of the zinc budget of a Texas Bay, Parker (1962) suggested that sediments act as a reservoir of zinc in an estuary. Zinc can move from sediments into the water through ion exchange processes or through the action of organisms intimately associated with the sediments. Also, radioactive zinc can be accumulated directly from the sediments by many bottom dwellers since sediment material often appears in the guts of these organisms (Anderson, Jones, and Odum, 1958).

Zinc-65 moved rapidly from the water to the biota. Oysters accumulated more zinc-65 and contained more stable zinc than the other organisms. Fish accumulated the least amount of zinc-65 of any organism and yet contained almost as much stable zinc as the oyster (Table 1).

TABLE 1 SPECIFIC ACTIVITY CALCULATIONS FOR SEDIMENTS AND ANIMALS EXPOSED TO $Zn^{65}$ IN A FLOWING WATER SYSTEM

| Component | Stable Zinc Content | $Zn^{65}$ Content | Specific Activity |
|---|---|---|---|
| | g Zn/g tissue | uc $Zn^{65}$/g tissue | uc $Zn^{65}$/g Zn |
| Oyster | $5.8 \times 10^{-5}$ | $2 \times 10^{-2}$ | 340 |
| Fish | $4.3 \times 10^{-5}$ | $8.2 \times 10^{-4}$ | 19 |
| Crabs | $2.7 \times 10^{-5}$ | $6.7 \times 10^{-3}$ | 240 |
| Sediment | $1.1 \times 10^{-5}$ | $2.1 \times 10^{-3}$ | 190 |
| Clams | $4.7 \times 10^{-6}$ | $2.1 \times 10^{-3}$ | 450 |
| Water | $2.2 \times 10^{-8}$ | $2.0 \times 10^{-5}$ | 910 |

However, the zinc-65 in the oyster appeared to have reached an "apparent steady state" with the zinc-65 in the water at the end of 21 days, while the zinc-65 content of the fish was increasing at this time (Figure 2). Since the specific activity of the water was still much higher than that of the biota, it is obvious that the system had not reached an equilibrium at the end of 21 days.

In order to evaluate the movement of radioactivity through a marine environment, it is necessary to know the rate of loss of the isotope from the components, as well as the rate of uptake. As illustrated in Figure 3, the rate of loss is not necessarily equal to the rate of uptake. When placed in sea water containing zinc-65, oysters, clams, and sediments attained maximum levels of zinc-65 within 15 days, yet only a small percent of this zinc-65 was lost from these components when they were placed in nonactive sea water for 15 days.

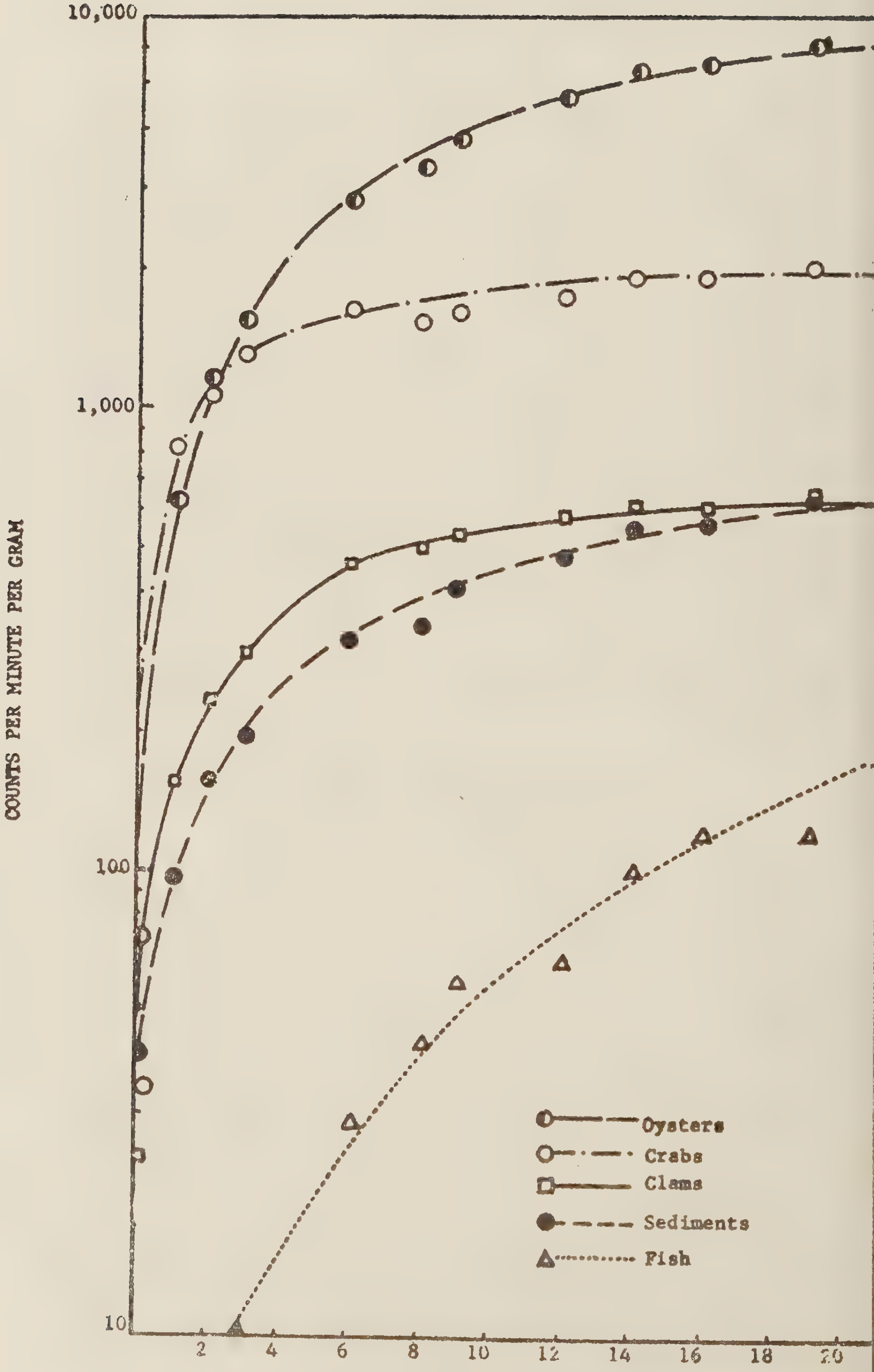

Figure 2. Accumulation of Zinc-65 by organisms.

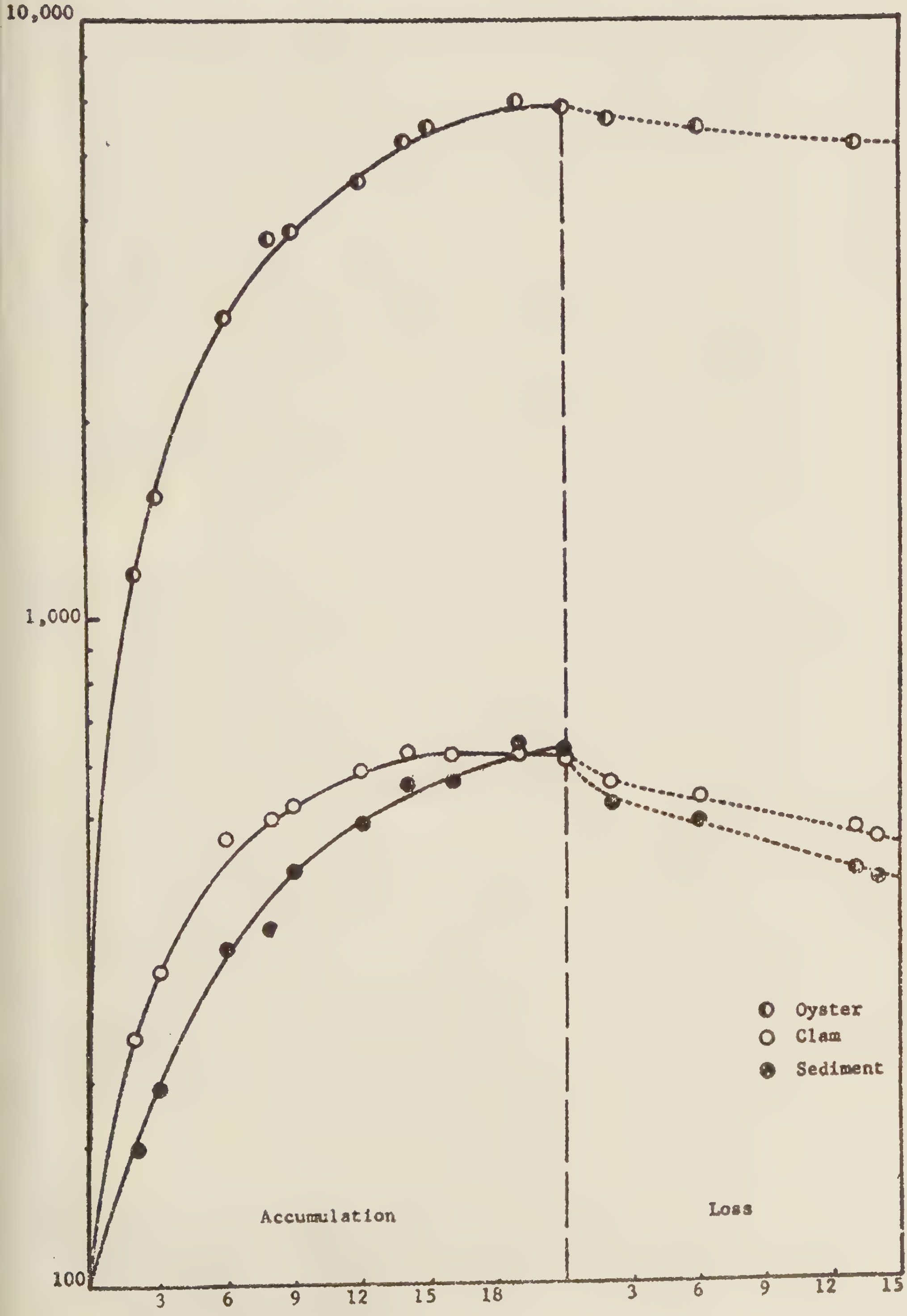

Figure 3. Accumulation and loss of $Zn^{65}$ by oysters.

A measure of the residence time of radioactive isotopes in organisms is the biological half-life (the time required for an organism to lose one-half of its radioactivity). Based on a 30-day loss experiment, the biological half-life for zinc-65 was calculated to be 150 days for the test oysters, and 51 days for the clams. Forty-two days were required for the sediments to lose one-half of their activity. This type of information would be especially helpful in predicting the time required for the level of radioactivity in an estuary to be reduced.

## MOVEMENT OF GOLD-199 THROUGH A MARINE COMMUNITY

The movement of radioactive gold through a marine community was observed in the laboratory and in nature. Recent interest by the Corps of Engineers in using radioactive gold to follow silt movement in the Cape Fear River near Southport, N. C., and the evident lack of information on the bio-acccumulation of this element in the marine environment, prompted the experiments with this isotope. This was an instance where laboratory experiments were needed to obtain data on the levels of accumulation of the isotope by the biota and rates of turnover for the element before it was released in the estuary. There were differences in the design of laboratory experiments and those conducted in the field. In experiments conducted in the laboratory, the radioactive gold solution was added directly to the water which was confined to a closed system. In the experiment in the river, the gold was sorbed onto sediment prior to being released into the river. The river water was subject to wind and tidal influence which resulted in a constant dilution of the radioactivity.

### Methods and Materials

The accumulation of gold by a community maintained in the laboratory was observed by placing 10 clams (*Mercenaria mercenaria*), six blue crabs (*Callinectes sapidus*), 10 minnows (*Cyprinodon variegatus*), and sediments in the form of montmorillonite clay in a fiberglass tank containing 1,000 liters of cotton-filtered sea water. Carrier-free gold-199 was added in the form of $AuCl_3$ to give a concentration of 14.2 microcuries per liter. Individual organisms were sampled at regular intervals, their radioactive content measured, and then returned to the tank. This procedure of determining the activity of the whole animal eliminated the need for sacrificing animals; thus the number of individuals was not reduced each time a sample was taken, and uptake by the same individuals could be followed throughout the experiment. The radioactivity in the samples was measured with a scintillation detector containing a three-inch crystal.

Radioactive gold sorbed onto sediments was introduced into the Cape Fear River using a method described by Krone (1960). Two loads of "labeled" sediment, each containing five curies of gold, were released by the Corps of Engineers into the river, the first on October 24, 1962, at 6:00 P.M., and the second on October 25, 1962, at 4:00 P.M. The movement of the gold was followed by measuring the amount of radioactivity in organisms in the river before and after the isotope was introduced, and in "test organisms" held in cages at the six stations shown in Figure 4 (Duke, Baptist and Hoss, 1963). These stations were selected so that the organisms would be exposed to different amounts of radioactivity. The test organisms at each station consisted of 25 blue crabs *(Callinectes sapidus)*, 50 oysters *(Crassostrea virginica)*, and 50 mummichogs *(Fundulus heteroclitus)*. In addition, plastic petri dishes containing montmorillonite clay were exposed at each station, and samples of water and natural bottom sediment were collected.

### Results and Discussion

Radioactive gold moved rapidly from the water to the biota and sediments in the laboratory experiment. Over half of the radioactive gold was removed from the water in 10 days. Results of laboratory experiments indicated that radioactive gold is particulate in sea water. This accounted in part for the rapid movement from the water. The short physical half-life of gold-199 (3.2 days) also contributed to the disappearance of the gold from the water. Although the element gold is not of particular biological importance, the manner in which the particulate material was cycled in the experimental environment is important since several of the elements that are essential for animal nutrition, such as iron, occur in the particulate form in sea water. Although each element will participate in the cycle according to its physical and chemical properties, the principles and methods involved in this study can be applied to investigations with other elements.

Due to the tremendous dilution by river water, strong currents, and short physical half-life of the gold isotope, only small amounts of radioactivity were present in water samples taken at sampling stations after release of the labeled sediment in the Cape Fear River. While little radioactivity was detected in the water samples, suspended material in the water did contain radioactive gold.

Samples of the bottom sediment at the various stations contained little radioactivity. Evidently the labeled sediment that was released was maintained in suspension and did not settle out in the sampling area. The montmorillonite clay that was placed near the bottom at

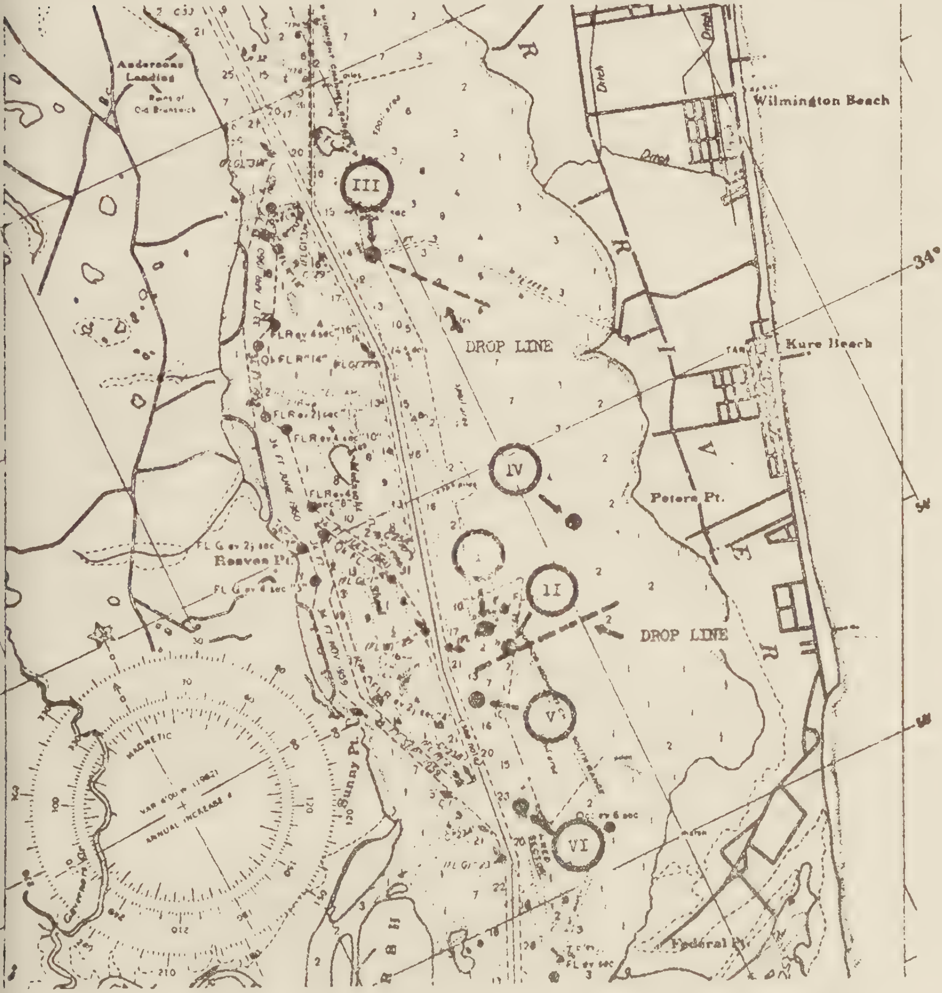

Figure 4. Location of sampling stations in the Cape Fear River.

several sampling stations contained a measurable amount of radioactive gold. This radioactivity could have originated from suspended sediment particles adhering to the surface of the clay, or from radioactive gold that was not initially sorbed onto sediments in the mixing chamber.

All of the animals in the laboratory accumulated radioactive gold from the water. Due to the particulate nature of gold in sea water and the lack of a definite physiological need for this element by marine organisms, surface absorption was probably the primary mode of accumulation. If the radioactivity of the water is considered as one, the relative concentration of the radioisotope by the organisms was as follows:

| | |
|---|---|
| Crabs | 4.5 |
| Sediments | 3.8 |
| Clams | 2.6 |
| Fish | 1.0 |

As indicated, crabs, whose carapace and relatively large gill surface areas offer excellent sorption sites for particulate material, accumulated the most activity. Results of the laboratory experiments showed that crabs and bottom dwelling filter feeders would accumulate more radioactive gold than the pelagic members of the estuary.

In the Cape Fear River, none of the test organisms maintained in the area where the radioactive gold was released accumulated as much of the radioactive gold as the laboratory animals. In fact, the amount of radioactive gold in the biota was barely detectable. Crabs from Station II contained higher concentrations of radioactivity than those of other stations. Trawl samples taken 41 hours after the first release of radioactive sediment between Stations III and VI, when monitored showed that the fish, crabs, and shrimp contained no measurable activity. There was no indication that indigenous organisms received or retained radioactive gold.

## SUMMARY

Upon introduction of a radionuclide into the water phase of an estuary, a form of "competition" for this material occurrs between the biota and the sediments. Depending upon their biological function and position in the replaceability series, some elements are accumulated more by one component than the other. Even though, in some instances, sediments are initially successful in removing large quantities of radionuclides from the water and thus preventing their uptake by the biota, this sediment-associated radioactivity may later affect many benthic species by exposing them to high levels of radiation. Also, any leaching of radioactivity from the sediments back to the water makes it again available for uptake by the biota. Even before the radioactivity is leached from the sediment, it may become available to the biota. This results from a variation in the strength of the bonds between the different radionuclides and the sediment particles. Loosely bound radionuclides can be "stripped" from particles of sediment and utilized by bottom feeding organisms.

Data obtained in the zinc-65 experiment could be of special interest to the ecologist interested in the flow of trace metals through the estaurine environment. A total of 157 microcuries of zinc-65 was flowed through the experimental environment. The biota and sediments accumulated a total of 6.8 microcuries, or 4.3 percent of the available zinc-65. These figures can apply only to this particular experimental design. However, the results do give an indication of how the isotope would move through the biota of an estuary.

Sensitive detection methods now permit rapid analysis of the movement of radionuclides through estuarine environments. By following a selected radioactive element through the cycle, information is obtained on the stable element of concern. In the future, the cycling of selected radionuclides can be followed when they are released directly into an estuary. However, before this is attempted, much information can be obtained from laboratory experiments involving communities of organisms.

The author gratefully acknowledges the assistance of colleagues on the staff of the Radiobiological Laboratory in collecting data for the laboratory and field experiments.

## LITERATURE CITED

Anderson, A. E., D. C. Jones, and H. T. Odum. 1958. Alteration of clay minerals by digestive processes of marine organisms. Sci., *127* (3291): 190-191.

Duke, T. W., J. P. Baptist, and D. E. Hoss. 1963. Biological implications of radioactive gold as a sediment tracer in the marine environment. In press.

Grant, Virginia. 1962. Personal communication.

Kraus, K. A., and G. E. Moore. 1953. Anion exchange studies. VI. The divalent transition elements. Jour. Amer. Chem. Soc., 75: 1460.

Krone, R. B. 1960. Methods for tracing estuarial sediment transport processes. Report for San Francisco District Corps of Engineers, U. S. Army. Contract No. DA-04-203, Civ. Eng.-59-99. 57 p.

Parker, P. L. 1962. Zinc in a Texas bay. Inst. Mar. Sci., Vol. 8: 75-80.

Vallee, B. L., and J. B. Gibson. 1948. An improved dithizone method for the determination of zinc in blood and tissue samples. Jour. Biol. Chem., 176: 435.

# Cycling of Zinc in Experimental Marine Environments

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The cycling of zinc, an essential trace element for the growth and development of marine organisms, was followed in experimental marine environments. A radioisotope of this element, zinc 65, was used as a tracer in these studies. Under controlled conditions in the laboratory, filter-feeding molluscs accumulated more zinc 65 and contained more stable zinc than other members of the community. Zinc 65 added to two experimental ponds moved rapidly from the water to sediments and biota. After 100 days, over 98 percent of the zinc 65 and stable zinc in the pond was in the sediments. Seaweed which entered one of the ponds 45 days after the experiment was started accumulated zinc 65 even though no detectable radioactivity was in the water.

Abstract reprinted from the *ASB Bulletin*,
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# Relation of Temperature to Fish Abundance and Distribution in the Southern New England Area.

BY R. L. EDWARDS

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# RELATION OF TEMPERATURE TO FISH ABUNDANCE AND DISTRIBUTION IN THE SOUTHERN NEW ENGLAND AREA.[1]

By

R. L. Edwards[2]

## ABSTRACT

Information is presented on the distribution of a number of species of southern New England fishes that typically migrate offshore during the winter months. Depth and temperature preferences are discussed. Seasonal changes in the abundance of eight species on an inshore fishing ground, the Southwest Ground near Block Island, are described for the period 1956-58. The relation of these changes to temperature is discussed. The seasonal changes observed on the Southwest Ground demonstrate that these species tend to be most abundant on inshore grounds when water temperatures are the same as those in which they occur most abundantly offshore. Some of the factors that complicate the analysis of seasonal changes in abundance are briefly discussed. These include size, sex, and the effect of temperature or other hydrographic events such as the fall overturn on availability.

## INTRODUCTION

The first United States Commissioner of Fisheries, S. F. Baird, undertook an investigation of the life histories of various commercial species common to the southern New England area by soliciting the testimony of knowledgeable fishermen, trap operators and others. To the question concerning the seasonal movements of scup, Mr W. E. Whalley of Newport, Rhode Island, replied as follows:

"They expected them in February, and got the seines ready. They had them in the water in March. I always judge by the dandelions; when I see the first dandelion, scup come in; I watch the buds, and when the buds are swelled full, then our traps go in. When the dandelion goes out of bloom and goes to seed, the scup are gone; that is true one year with another, though they vary with the season. I am guided by the blossoms of other kinds of plants for other fish. When high blackberries are in bloom, we catch striped bass that weigh from twelve to twenty pounds; when the blue violets are in blossom—they come early—you can catch the small scoot-bass. That has always been my rule, that has been handed down by my forefathers".

Although this testimony is nearly 100 yr old, it is not easy to improve upon it today.

Fishery biologists tacitly agree that temperature is an important factor in the determination of general distribution and seasonal abundance. It is difficult however to demonstrate and quantify the role of temperature, simply because of the lack of concomitant fishery and temperature data for most marine areas; and because of the difficulty of establishing the causality involved in implied relationships. While much still remains to be desired, the general temperature cycle is well known and abundant fishery data exist for the southern New England area, sufficient at least to justify a study of the relation of temperature to variations in seasonal abundance.

Early in the 1950's, a sizeable industrial trawl fishery developed in New England, particularly at Point Judith, Rhode Island. This fishery was unusual in that all fish taken in the trawl were landed. Food fish were sorted out and sold at the local cooperative, and the rest of the catch sold at a nearby reduction plant. The general aspects of this fishery have been reported upon by Edwards and Lux (1958). The species composition of that portion of the catch sold for reduction in 1957 and 1958 has been reported by Edwards (1958) and Edwards and Lawday (1960). By 1960 this fishery virtually ceased to exist at Point Judith. The fishing activities had however been carefully documented for the period July 1955-60 inclusive.

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[1] Originally Contribution No. A-16, ICNAF Environmental Symposium, Rome 27 January-1 February 1964.

[2] Bureau of Commercial Fisheries Biological Laboratory, Woods Hole, Massachusetts, USA.

## DIVERSITY INDEX STUDIES

The first attempt to interpret the industrial trawl fishery data involved the calculation of various indices of species diversity, especially Fisher's (Fisher, *et al.*, 1943) alpha[3]. There was a relation between bottom temperature and alpha, particularly on those fishing grounds nearest to land. The values of alpha obtained for one of these, the Southwest Ground, are given in Table 1. Combining samples, as for example the bimonthly combinations given in Table 1 or the combining of samples from nearby grounds of the same depth, tended to strengthen the relation between temperature and alpha, and suggested as well that very large samples were required to obtain reliable values for individual grounds or smaller units of time. As it was, over 55,000 fish were involved in the Southwest Ground samples used for the analysis summarized in Table 1.

TABLE 1. ALPHAS FOR SOUTHWEST GROUND, FOR 1956-58, BY MONTH, FOR ALL MONTHLY SAMPLES COMBINED, AND FOR EACH BIMONTHLY PERIOD, ALL SAMPLES COMBINED.

|  | 1956 | 1957 | 1958 | Average alpha | Alpha, all samples combined | Alpha bimonthly values, all samples combined |  | Bottom water temperature °C |
|---|---|---|---|---|---|---|---|---|
| Jan. | 2.16 | 3.13 | -- | 2.65 | 2.55 | +Feb. | 2.45 | 6.0 |
| Febr. | 1.76 | 1.98 | 2.53 | 2.09 | 2.01 | +Mar. | 2.39 | 3.8 |
| Mar. | 2.69 | 2.36 | 2.48 | 2.51 | 2.42 | +Apr. | 2.92 | 3.3 |
| Apr. | 3.54 | 2.67 | 2.69 | 2.97 | 2.80 | +May | 3.07 | 4.8 |
| May | 2.80 | 2.78 | 2.89 | 2.82 | 3.00 | +June | 3.32 | 7.0 |
| June | 2.80 | 2.56 | 3.31 | 2.89 | 3.30 | +July | 3.68 | 11.2 |
| July | 2.93 | 3.23 | 2.87 | 3.01 | 3.55 | +Aug. | 3.78 | 12.0 |
| Aug. | 2.65 | 2.86 | 2.36 | 2.62 | 3.22 | +Sept. | 3.77 | 13.3 |
| Sept. | 2.90 | 3.09 | 3.18 | 3.06 | 3.38 | +Oct. | 3.59 | 14.2 |
| Oct. | 2.82 | 3.26 | 3.01 | 3.03 | 3.58 | +Nov. | 3.91 | 14.2 |
| Nov. | 2.46 | 2.28 | 3.09 | 2.61 | 3.35 | +Dec. | 3.20 | 12.6 |
| Dec. | 2.60 | 2.41 | 2.47 | 2.49 | 2.45 | +Jan. | 2.77 | 7.0 |

## SOUTHERN NEW ENGLAND SPECIES

In very broad terms, the species in the southern New England area may be divided into two groups. The first is a summer or warm water complex, and includes the red hake (*Urophycis chuss*), silver hake (*Merluccius bilinearis*), scup (*Stenotomus chrysops*), butterfish (*Poronotus triacanthus*), fluke, or summer flounder (*Paralichthys dentatus*), angler (*Lophius americanus*) and about twenty additional species of lesser abundance. Most of these species migrate offshore and southward to the edge of the Continental Shelf during the winter months. During the cold months of the year, a second group of species, fewer in number and considerably smaller in biomass, dominate the grounds. The group includes, among others, the cod (*Gadus morhua*), ocean pout (*Macrozoarces americanus*), yellowtail flounder (*Limanda ferruginea*) and the longhorned sculpin (*Myoxocephalus octodecimspinosus*). During the warmer months of the year these species either move offshore or eastward toward the Gulf of Maine.

## WINTER DISTRIBUTION

The fishes characteristically occurring inshore during the warm months of the year migrate offshore and southward during the winter months as mentioned above. During winter months as shown in Fig. 1., inshore water temperatures approach 0°C. Temperatures increase rapidly with depth, reaching a maximum of 12° to 14°C. between 100 and 125 m. This warm water zone is characteristic of the shelf edge from Cape Cod to Cape Hatteras. Beyond the warm zone temperatures slowly decrease as depth increases, but seldom decrease to much less than 6°C. at 250 m.

The numbers of individuals of some of the species collected at the time the data for Fig. 1 were obtained are given in Table 2. More extensive distributional data were obtained in 1959 on

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[3] $S = \alpha \ln (N/\alpha+1)$, where S is the number of species and N the total number of individuals.

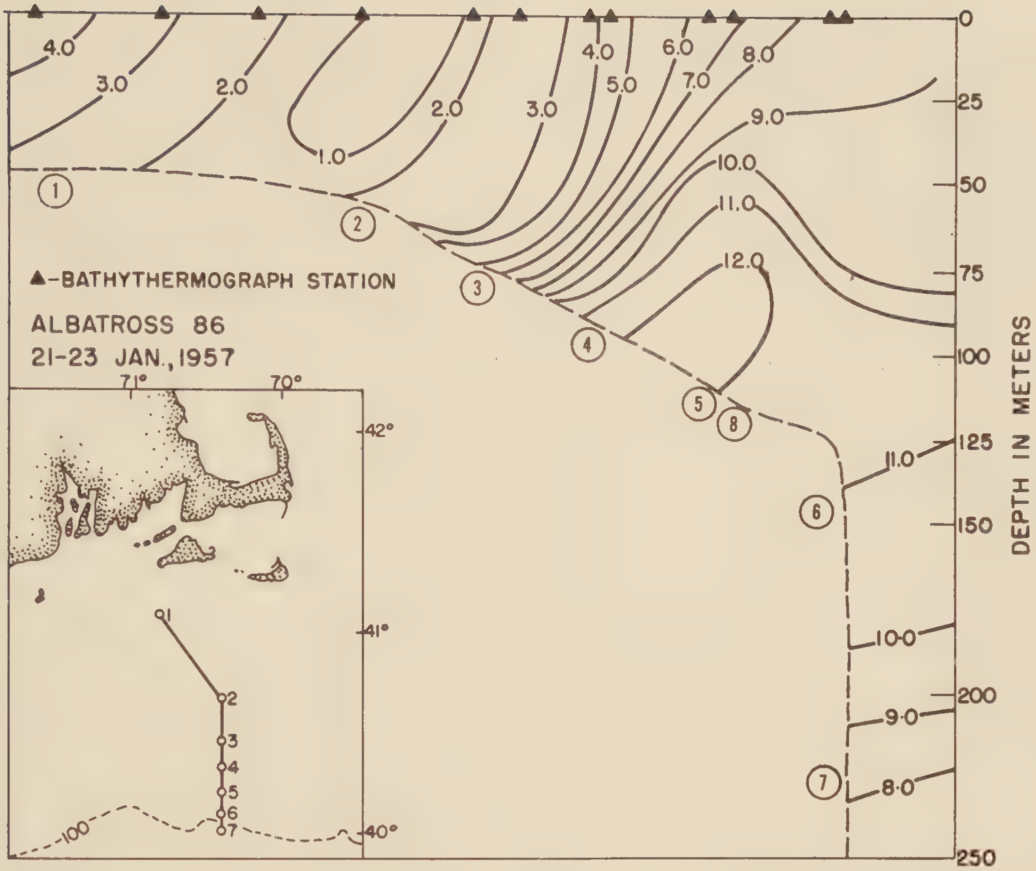


Fig. 1. Water temperatures and fishing station locations (circled), based on data collected on *Albatross III* cruise 86, 21-23 January, 1957. Transect runs south from Martha's Vineyard.

*Albatross III* Cruise 126 (Edwards, *et al.* 1961). These data are presented diagrammatically in Fig. 2. The values given represent the relative (percent) number per tow for each temperature interval given. The number of tows was insufficient to break down the data for temperatures less than 10°C.

Two species, the scup and fluke, were most abundant in the warmer water and both were more abundant on the shoaler side of the warm water zone. The fluke was not often taken on this particular cruise and the data obtained indicate a sample bias toward colder water not in accord with other observations, as for example those of Cruise 86 given in Table 2.

The butterfish was most abundant in waters with a temperature of about 11° C , regardless of depth. Similarly distributed, but with a preference for even colder water (9° to 10°C ), the red hake also appeared to disregard depth.

While the angler was most frequently taken in water of any depth with temperatures from 8° to 9°C , it was clearly more abundant at depths of 125-200 m. Silver hake as well tended to be more abundant in deeper water but generally did not occur where temperatures were much below 9°C except for young-of-the-year silver hake which were taken only in the relatively cold shoal water. A general tendency for this species to prefer progressively warmer water as it increases in size was observed.

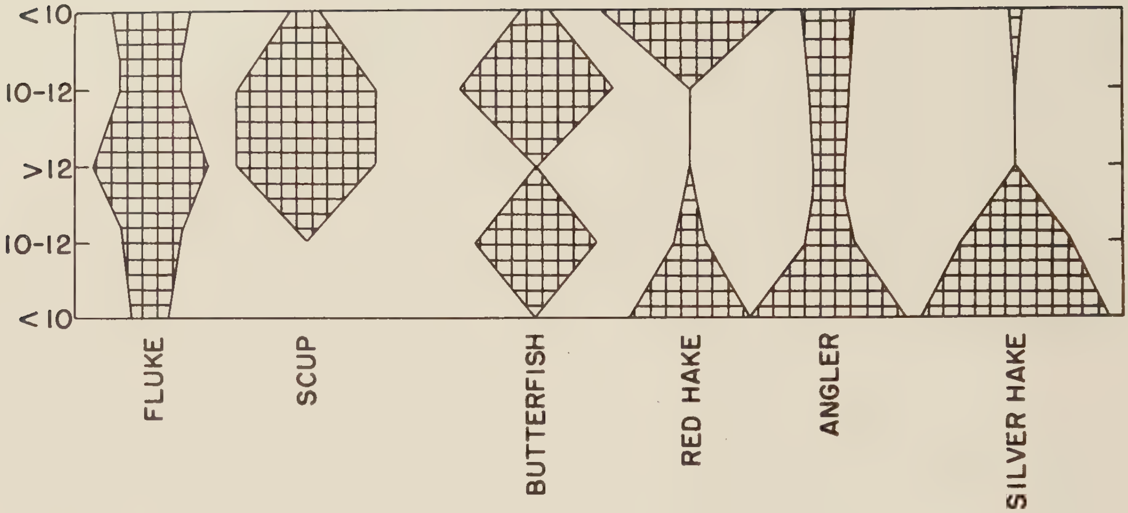
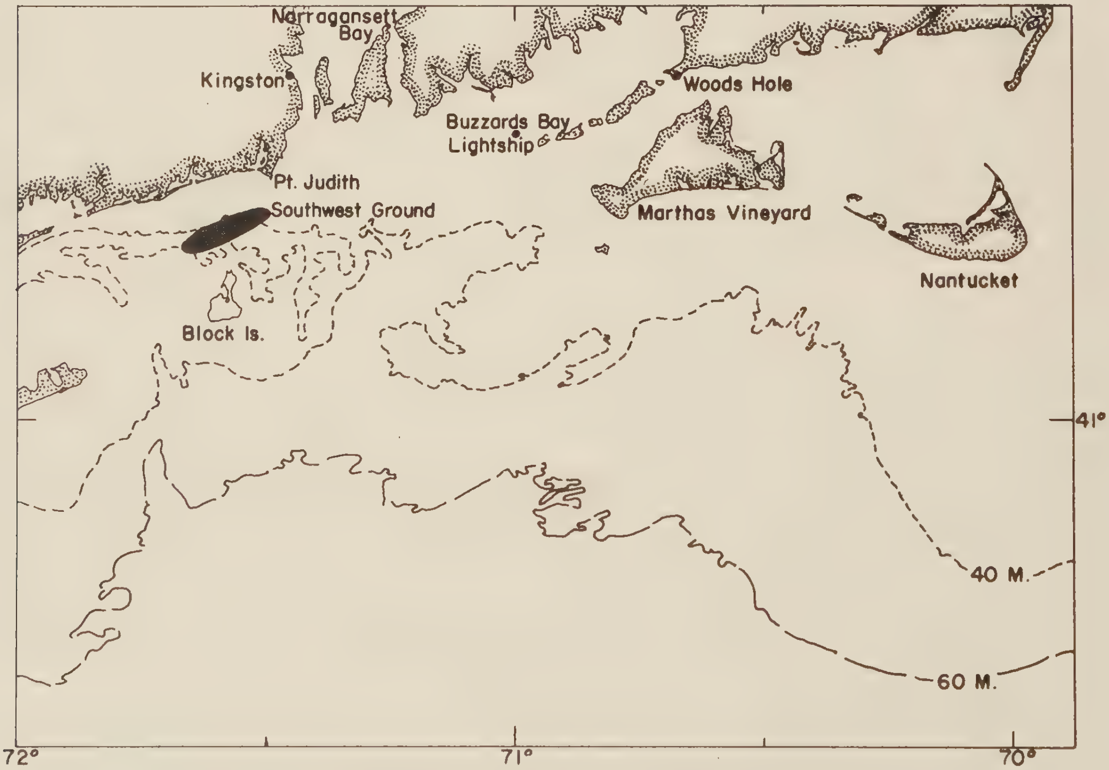


Fig. 2. Diagrammatic presentation of the relative (percentage) catch/tow data. Depth increases from top to bottom, the warmest water occurs between 100-125 m.



Narragansett Bay
Kingston
Woods Hole
Buzzards Bay Lightship
Pt. Judith
Southwest Ground
Marthas Vineyard
Nantucket
Block Is.
41°
40 M.
60 M.
72°
71°
70°

Fig. 3. Map of the southern New England area showing location of Southwest Ground and surface temperature stations.

TABLE 2. NUMBERS OF SELECTED SPECIES CAUGHT AT STATIONS SHOWN ON FIG.1. ASTERISK INDICATES YOUNG-OF-THE-YEAR.

| | STATION NUMBER | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 8 | 6 | 7 |
| Bottom temperature °C | 2.8 | 2.2 | 6.7 | 11.1 | 11.9 | 11.6 | 11.0 | 8.4 |
| Depth (m) | 50 | 60 | 70 | 85 | 110 | 115 | 145 | 230 |
| Fluke | | | | 12 | 5 | | | |
| Scup | | | | 19 | 1 | | | |
| Butterfish | | | | 695 | 21 | | | |
| Red hake | | 18 | 102 | 1 | | | | |
| Silver hake | *6 | *560 | 223 | 11 | | 1 | | 28 |
| Angler | 2 | 6 | 7 | 1 | | 1 | | 6 |
| Cod | | 9 | | | | | | |
| Ocean pout | 1 | 2 | | | | | | |

## SEASONAL CHANGES ON THE SOUTHWEST GROUND

Water temperatures.

The Southwest Ground (Fig. 3) lies between Block Island and the coast of Rhode Island. The depths fished by commercial fishermen varied from 40 to 50 m. The seasonal cycle of temperature for waters 50 m in depth in this immediate area is shown in Fig. 4. Temperature minima of about 3°C occur in late February or early March, and maxima of about 20°C at the surface in August and 15°C at the bottom in September and October. Overturn begins toward the end of September and usually is complete by the end of October. Intrusions of colder bottom water in late summer almost certainly occur from time to time.

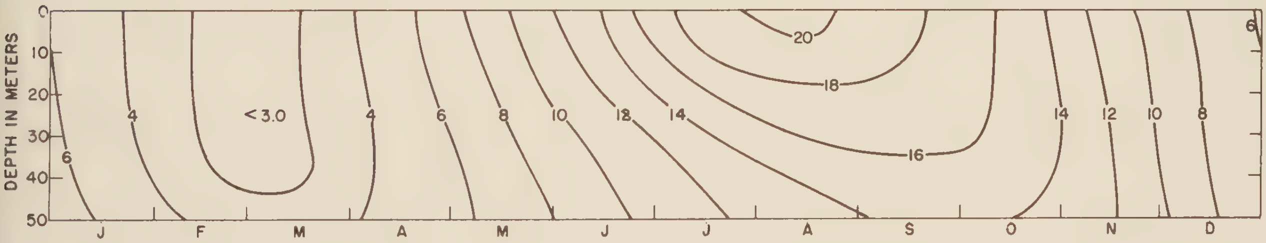


Fig. 4. Seasonal cycle of temperature for waters 50 meters in depth north of Block Island. Based on all bathythermograph data available for the period 1941-1960.

Fishery data will be presented below for the years 1956-58. The only consistently useful temperature data for this period are to be found in the surface temperature and lightship observations reported by Bumpus (1957) and Day (1959*a*, *b*). The year 1957 was a relatively warm year throughout the area south of Cape Cod. Day noted several instances of cold bottom water intrusion along the middle Atlantic coast in 1957. The data for 1958 show a tendency toward much colder water than was recorded in the previous several years. Surface temperatures at Woods Hole show the same general trends as do those at the Buzzards Bay Lightship and Kingston, Rhode Island. The records for the latter two stations are, unfortunately, incomplete for the period 1956-58.

Woods Hole surface temperature deviations for the period 1956-58 are presented in Fig. 5. The data have been smoothed by 3's to emphasize trends and reduce strictly local variations.

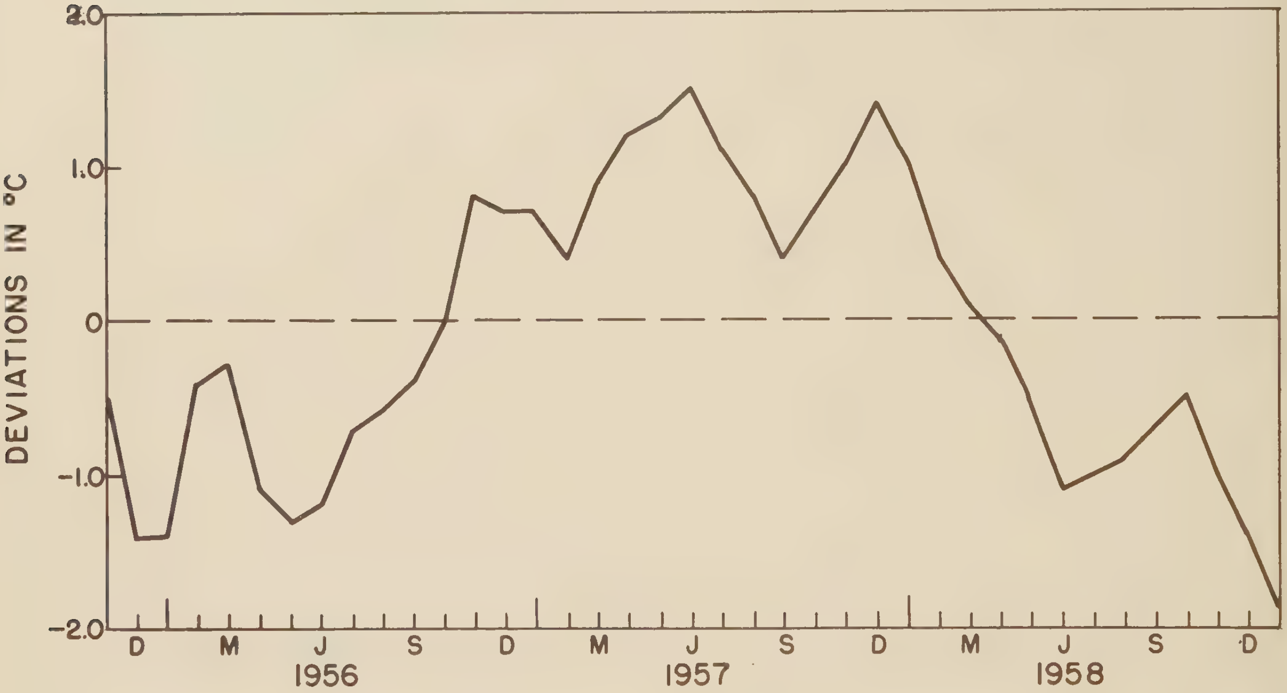


Fig. 5. Monthly deviations of Woods Hole surface temperatures, smoothed by 3's, for the period November 1955 to January 1959.

To the extent that these Woods Hole temperature deviations may also represent trends on the Southwest Ground, the following points should be kept in mind in connection with the discussions that follow. The year 1956 began relatively cold but warmed up gradually and ended with above normal temperatures. Conditions during 1957 were consistently warmer than normal. The sharp decline in the deviations for the summer months may indicate that the cold water intrusions mentioned earlier occurred in the southern New England area as well. The combination of warmer than average surface conditions and intrusions of colder bottom water would tend to delay overturn. Beginning with temperatures significantly above normal, 1958 temperatures became progressively colder than average and the year ended with below normal temperatures. It may be assumed that bottom temperatures varied in much the same manner except for that period (June - September) when thermal stratification was marked.

Catch/hour data

Table 3 lists the average monthly catch/hour for the eight species discussed below. Data are presented for the period 1956-58. The Southwest Ground is fished only during daylight hours; thus no adjustment was required for diurnal variations in availability. The vessels that prosecuted this fishery were all small otter trawlers, mostly less than 20 m in length. The codends of the trawls were invariably lined with netting having a stretched mesh size of 5 - 6 cm.

For the purposes of discussion, these data were transformed into relative (percentage) catch/hour figures for each year separately to eliminate the bias caused by variation in year class strength.

Fluke;Fig. 6,7

Fluke first arrive in moderate abundance in May and June and are most abundant on the Southwest Ground at the time of maximum bottom temperatures as shown in Fig. 6a. The data for each year separately show essentially the same changes, September in each case showing maximal relative abundance. Fish were on the grounds for the longest period in 1957, arriving in measurable numbers in March. They were present for the shortest period in 1958. In the spring these fish move through the grounds to other areas that are both shoaler and warmer at this time. As temperatures increase, the fluke gradually leaves the shoaler waters and the abundance again slowly increases on the Southwest Ground. At or about the time of overturn (data to establish the exact dates of overturn for the Southwest Ground do not exist) there is usually a marked increase in the catch/hour for a short period of time after which fluke rapidly depart from the ground. The bar diagram of the changes in catch/hour on a 5 day period basis, Fig. 7, illustrates this point. The somewhat anomalous data for 1957 are especially interesting in view of the postulated delay of overturn.

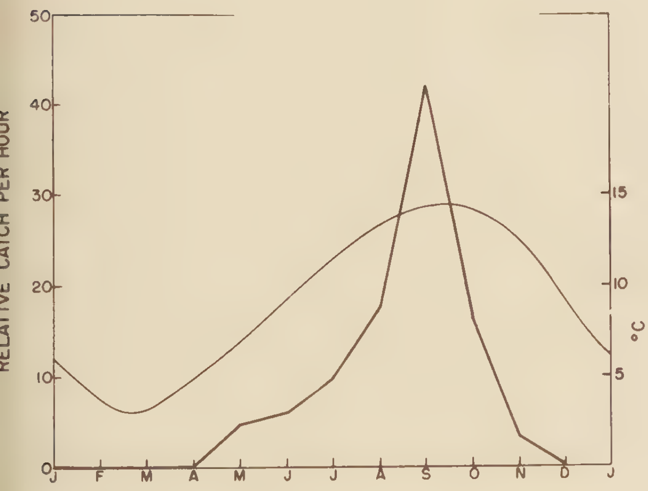


Fig. 6a. Seasonal changes in fluke abundance on the Southwest Ground, for the period 1956 through 1958, and average bottom temperature.

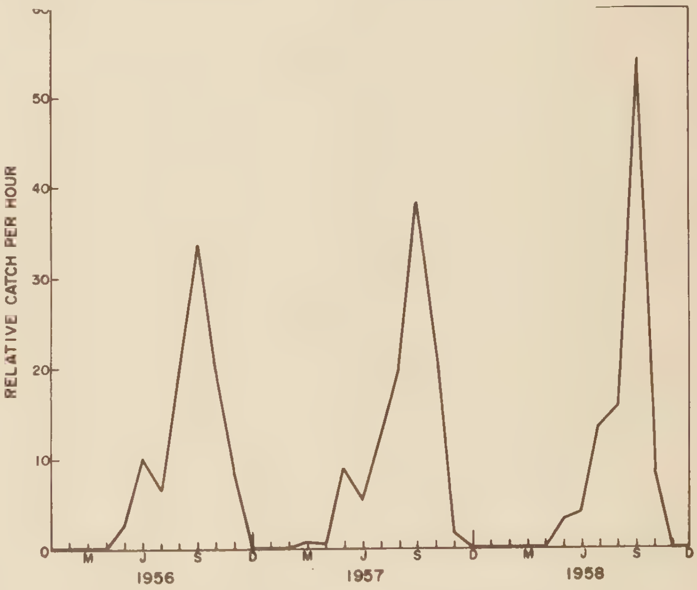


Fig. 6b. Yearly variation in seasonal changes of fluke abundance.

Scup; Fig. 8

The scup shows approximately the same seasonal abundance changes as the fluke. They first appear in number in April or May, at which time they are on their way to inshore spawning grounds where the water temperatures average 8° to 10°C. They move into deeper water as the season progresses and are most abundant at the time of highest bottom temperatures. Again as was the case with the fluke, they were present for the longest period of time in 1957. The offshore migration of the scup also begins at about the time of overturn and they are virtually gone from inshore grounds in November.

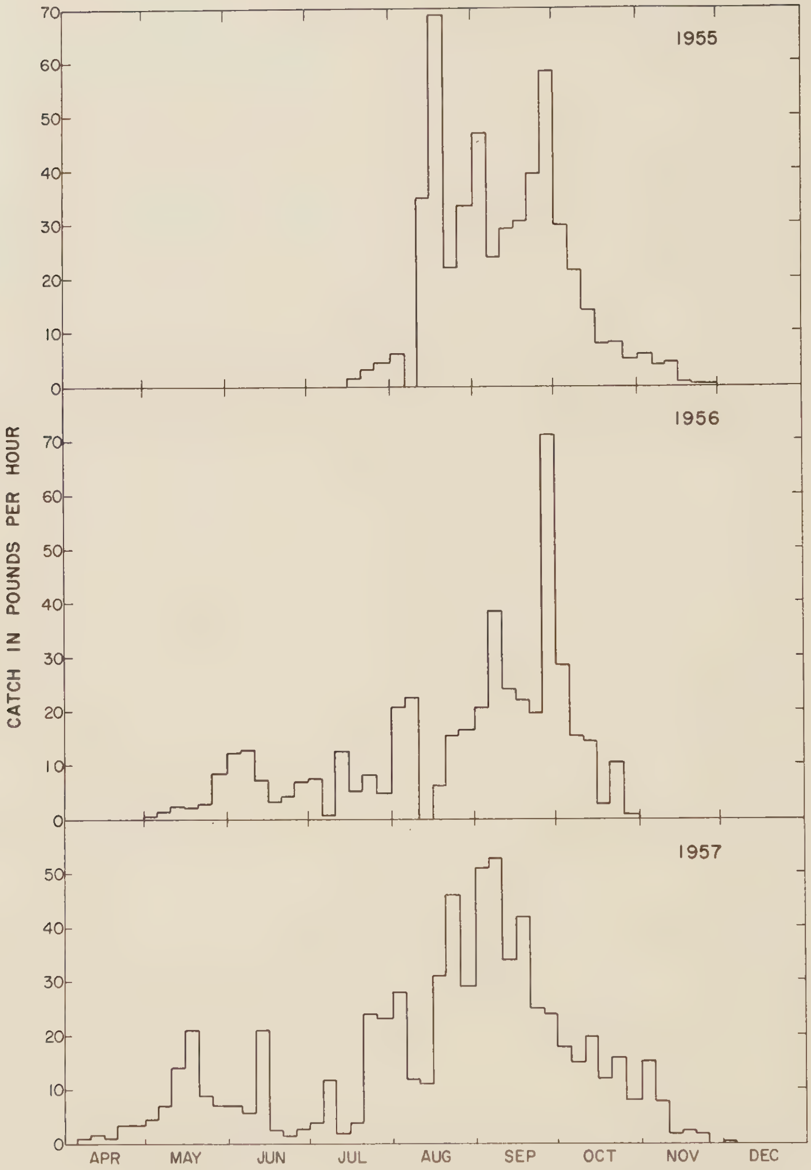


Fig. 7. Variation in the catch/hour of fluke on the Southwest Ground by 5 day periods, July 1955-December 1957.

Butterfish; Fig. 9

The butterfish is a widely ranging, quasi-pelagic species. Unlike the scup and fluke it frequently occurs in considerable numbers during the summer in the Gulf of Maine to the north and east. Historically its occurrence on the Southwest Ground is more erratic than any of the other principal species. Butterfish reach their peak seasonal abundance in November when the water temperature at the bottom is around 12°C. This species showed up earliest (April) in 1957 and generally was more abundant throughout the season in this year.

TABLE 3. CATCH PER HOUR TO NEAREST POUND OF VARIOUS SPECIES ON THE SOUTHWEST GROUND, BY MONTH, 1956 THROUGH 1958.

| Species | | Jan. | Feb. | Mar. | Apr. | May | June | July | Aug. | Sept. | Oct. | Nov. | Dec. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Fluke | '56 | -- | -- | -- | + | 2 | 8 | 6 | 15 | 28 | 17 | 7 | + |
| | '57 | + | -- | 1 | + | 7 | 4 | 1 | 16 | 30 | 19 | 1 | -- |
| | '58 | -- | -- | -- | + | 3 | 4 | 13 | 14 | 50 | 8 | + | -- |
| | Average | -- | -- | + | + | 4 | 5 | 9 | 15 | 36 | 14 | 3 | + |
| Scup | '56 | -- | -- | -- | -- | 13 | 4 | 17 | 21 | 41 | 76 | 1 | + |
| | '57 | -- | -- | -- | 1 | 6 | 4 | 5 | 12 | 8 | 15 | 2 | -- |
| | '58 | -- | -- | -- | -- | 19 | 26 | 33 | 52 | 82 | 33 | 1 | + |
| | Average | -- | -- | -- | + | 13 | 12 | 18 | 28 | 44 | 41 | 1 | + |
| Butterfish | '56 | -- | -- | -- | -- | + | 4 | 3 | 6 | 2 | 3 | 45 | 19 |
| | '57 | + | -- | -- | + | + | 3 | 3 | 12 | 36 | 46 | 158 | 4 |
| | '58 | + | -- | -- | -- | + | 2 | 1 | 10 | 3 | 7 | 4 | 16 |
| | Average | + | -- | -- | + | + | 3 | 2 | 9 | 14 | 19 | 69 | 13 |
| Silver hake | '56 | 40 | -- | + | 1 | 183 | 269 | 504 | 557 | 987 | 1048 | 1889 | 817 |
| | '57 | 292 | 285 | 30 | 79 | 356 | 735 | 423 | 865 | 731 | 841 | 624 | 414 |
| | '58 | 98 | 8 | 3 | 1 | 145 | 187 | 300 | 558 | 603 | 552 | 338 | 507 |
| | Average | 144 | 98 | 11 | 27 | 228 | 397 | 409 | 660 | 774 | 814 | 951 | 579 |
| Red hake | '56 | 5 | -- | -- | 4 | 512 | 334 | 127 | 256 | 378 | 451 | 580 | 194 |
| | '57 | 30 | 17 | 10 | 42 | 364 | 529 | 175 | 289 | 70 | 81 | 119 | 43 |
| | '58 | -- | 5 | 4 | 9 | 513 | 279 | 117 | 128 | 363 | 456 | 1167 | 291 |
| | Average | 12 | 7 | 5 | 18 | 463 | 381 | 140 | 224 | 270 | 329 | 622 | 176 |
| Angler | '56 | 75 | -- | 19 | 8 | 86 | 123 | 101 | 16 | 54 | 30 | 35 | 167 |
| | '57 | 60 | 71 | 79 | 57 | 25 | 124 | 88 | 129 | -- | 47 | 109 | 378 |
| | '58 | 319 | 24 | 18 | 35 | 169 | 209 | 232 | 114 | 125 | 128 | 161 | 157 |
| | Average | 151 | 32 | 39 | 33 | 93 | 152 | 140 | 86 | 60 | 68 | 102 | 234 |
| Ocean pout | '56 | 51 | 220 | 392 | 103 | 186 | 37 | -- | -- | -- | -- | -- | 172 |
| | '57 | 223 | 478 | 445 | 296 | 307 | 42 | 16 | + | -- | -- | -- | 4 |
| | '58 | 44 | 378 | 440 | 463 | 212 | 38 | 22 | + | 2 | -- | 5 | 6 |
| | Average | 106 | 359 | 429 | 288 | 235 | 39 | 13 | + | 1 | -- | 2 | 61 |
| Cod | '56 | 40 | 61 | 56 | 11 | 6 | 4 | + | -- | + | 1 | 60 | 41 |
| | '57 | 25 | 26 | 25 | 9 | 1 | + | + | -- | -- | + | 46 | 48 |
| | '58 | 41 | 71 | 39 | 30 | 9 | + | + | + | + | 6 | 70 | 74 |
| | Average | 35 | 53 | 40 | 16 | 5 | 1 | + | + | + | 2 | 59 | 54 |

Silver hake; Fig. 10

Seasonal changes in relative abundance closely follow the seasonal temperature changes. Peak abundance is indicated for November but it should be noted (Table 3) that this may be the result of an atypical situation in November 1956. As mentioned before, the larger the silver hake, the warmer the water they appear to prefer. In 1956 the maximum lengths of silver hake sampled on the inshore grounds near Point Judith were as follows:

| | |
|---|---|
| Jan. - Mar. | 28 cm |
| Apr. - June | 40 cm |
| July - Aug. | 50 cm |
| Sept. - Dec. | 40 cm |

The fish were on the Southwest Ground for the shortest period in 1956, and year round in 1957 and 1958.

This species also occurs in the Gulf of Maine in commercial quantities during the summer months. During the early 1950's when water temperatures generally showed marked deviations on the warm side, occasional catches of silver hake were recorded from the Gulf of Maine during the winter months. Usually they depart this area early in the fall.

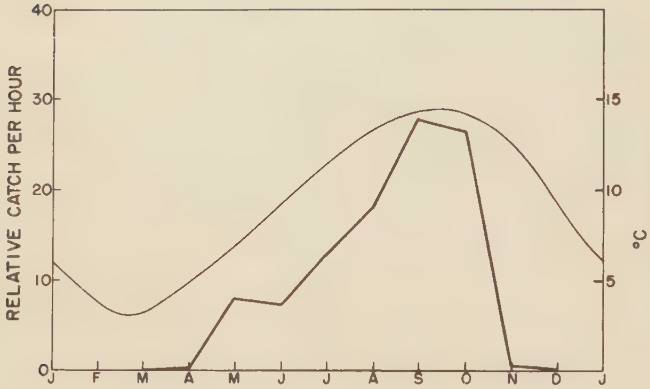


Fig. 8a. Seasonal changes in scup abundance on the Southwest Ground, for the period 1956 through 1958, and average bottom temperature.

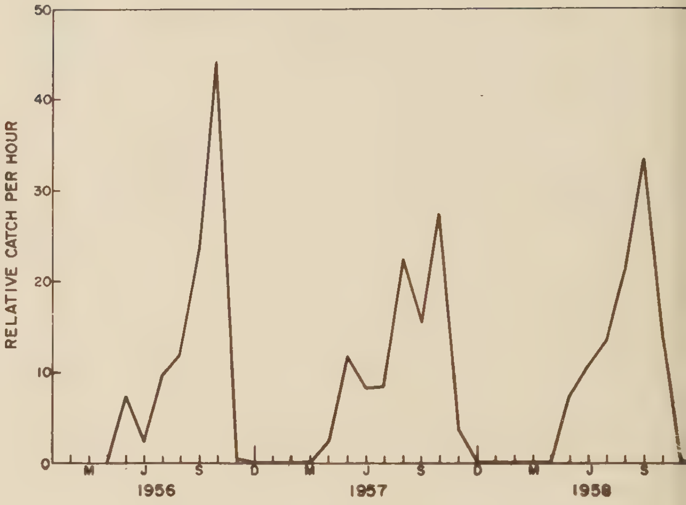


Fig. 8b. Yearly variation in seasonal changes of scup abundance.

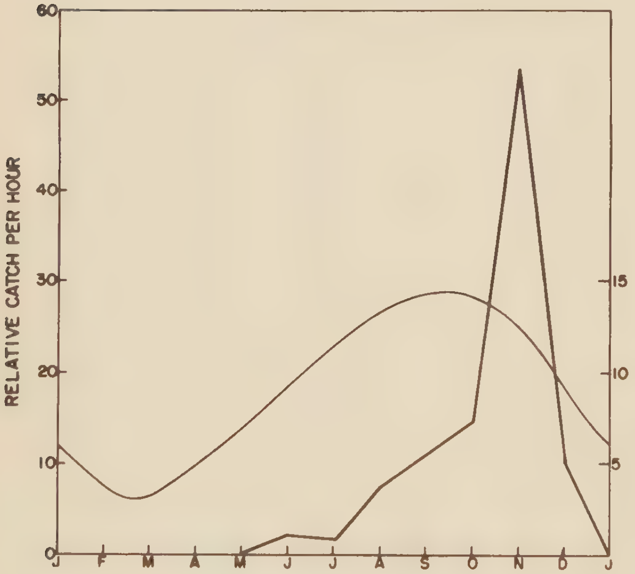


Fig. 9a. Seasonal changes in butterfish abundance on the Southwest Ground, for the period 1956 through 1958, and average bottom temperature.

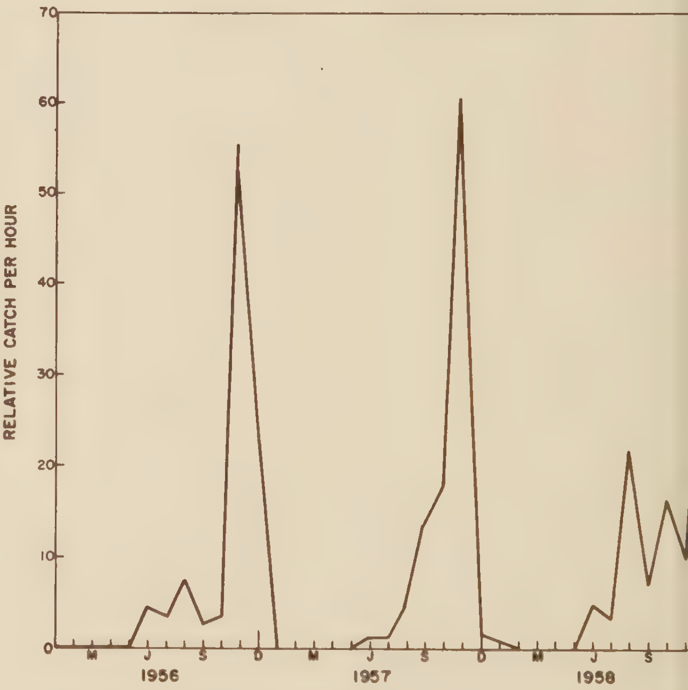


Fig. 9b. Yearly variation in seasonal changes of butterfish abundance.

Red Hake; Fig. 11

Red hake move into the Southwest Ground in great abundance late in April or early in May. As the waters warm this species tends to move into deeper, colder water to return again in number following the time of overturn. The species was on the ground throughout 1957, although generally less abundant than in 1956 or 1958. It did not return to the ground in number in the fall of 1957, probably because of the atypical hydrographic events of the year.

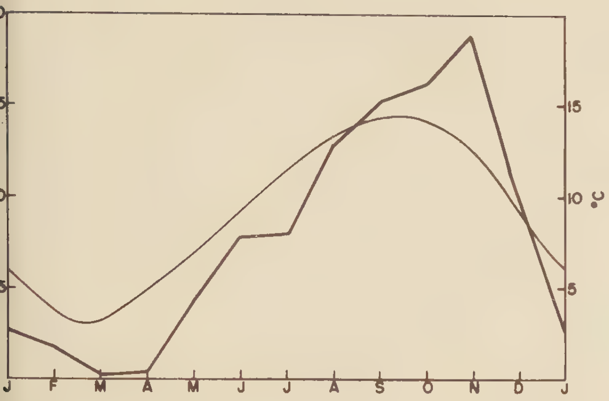


Fig. 10a. Seasonal changes in silver hake abundance on the Southwest Ground, for the period 1956 through 1958, and average bottom temperature.

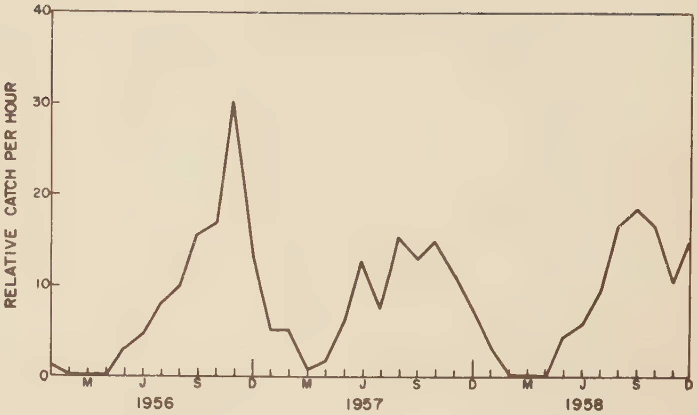


Fig. 10b. Yearly variation in seasonal changes of silver hake abundance.

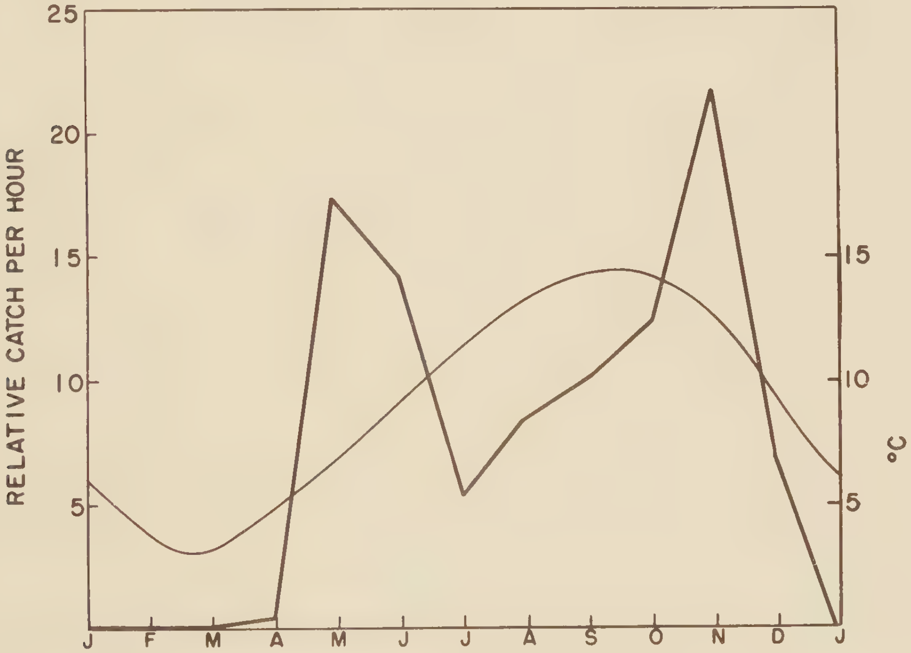


Fig. 11a. Seasonal changes in red hake abundance on the Southwest Ground, for the period 1956 through 1958, and average bottom temperature.

Angler; Fig. 12

The angler shows essentially the same type of seasonal variation in abundance as the red hake but with a preference for colder water. It is most abundant when the temperatures are about 9°C. It was present throughout 1958, the year that began relatively warm and finished on the cold side. It was entirely absent from the ground in September of 1957.

Both the angler and the red hake may occur on the ground throughout some years. Both as well occur as far north at least as the Grand Bank off Newfoundland.

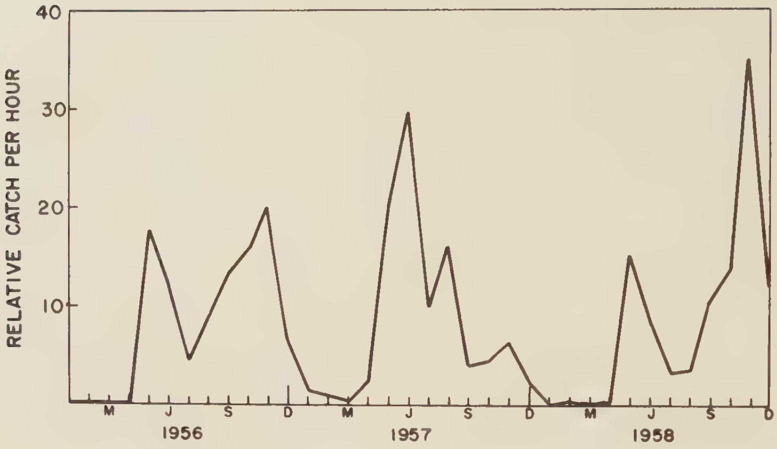


Fig. 11b. Yearly variation in seasonal changes of red hake abundance.

Ocean pout; Fig. 13

The ocean pout is clearly most abundant when water temperatures reach their minimum. They were present longest in 1958, but most abundant in terms of catch/hour in 1957. There is no substantial evidence, observational or otherwise, to suggest that the ocean pout undertakes migrations of any consequence. Olsen and Merriman (1949) have presented evidence that ocean pout are to be found on rougher, rocky bottoms, where they spawn in the summer and fall. It is suggested therefore that the changes observed may represent merely a local shift in habitat in response to temperature changes.

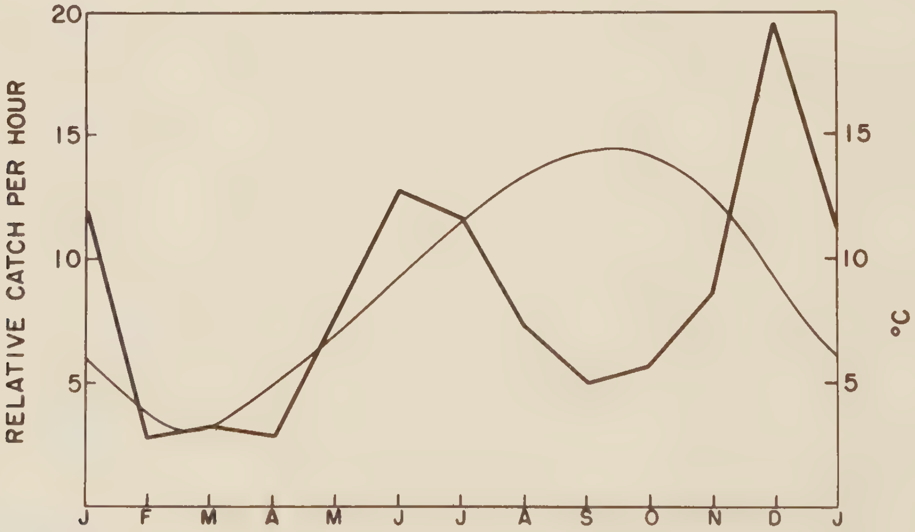


Fig. 12a. Seasonal changes in angler abundance on the Southwest Ground for the period 1956 through 1958, and average bottom temperature.

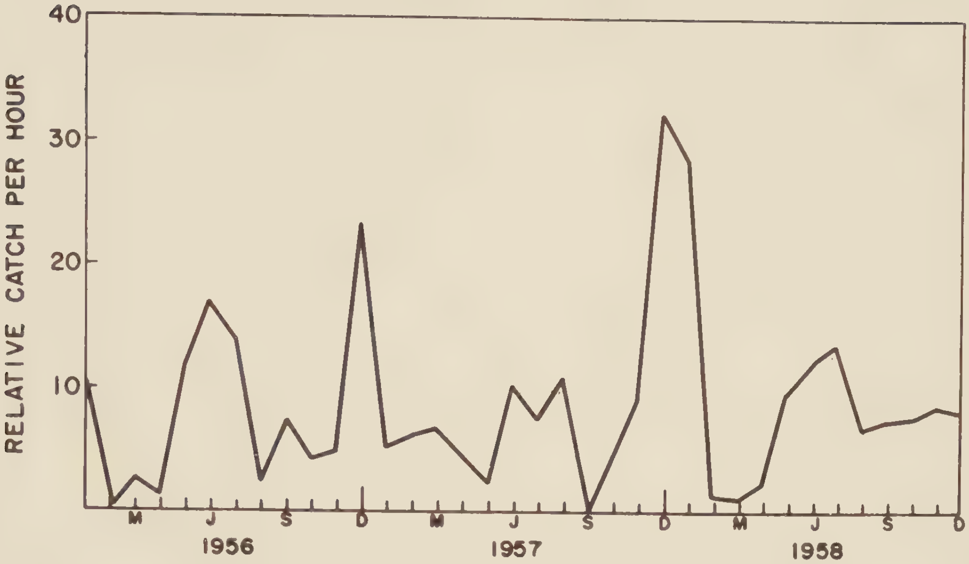


Fig. 12b. Yearly variation in seasonal changes of angler abundance.

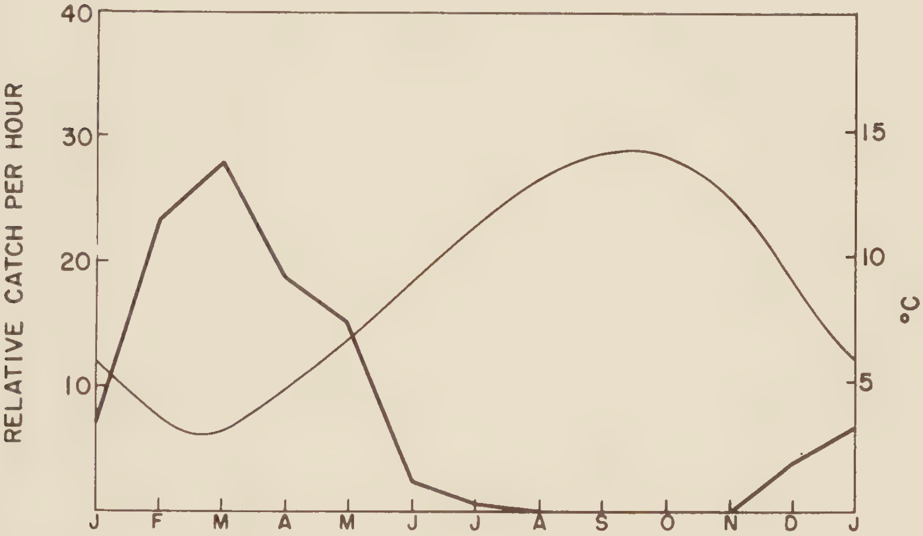


Fig. 13a. Seasonal changes in ocean pout abundance on the Southwest Ground for the period 1956 through 1958, and average bottom temperature.

Cod; Fig. 14

The cod shows essentially the same changes in seasonal abundance as the ocean pout, with the difference however that these changes are clearly associated with movements. The first peak in abundance represents a migratory wave that can be followed to the southern coast of New Jersey where these fish spawn. This group of fish arrives about 1 month after overturn. Occurring with these fish are other cod, possibly a local subgroup, which remain in the area throughout the winter (Bigelow and Schroeder, 1953, p. 186). The cod returning from the New Jersey spawning grounds do not pass through the inshore fishing grounds and thus do not show up on the Southwest Ground. The catch/hour in 1957 was considerably below that of the other 2 yr. Cod were present throughout 1958.

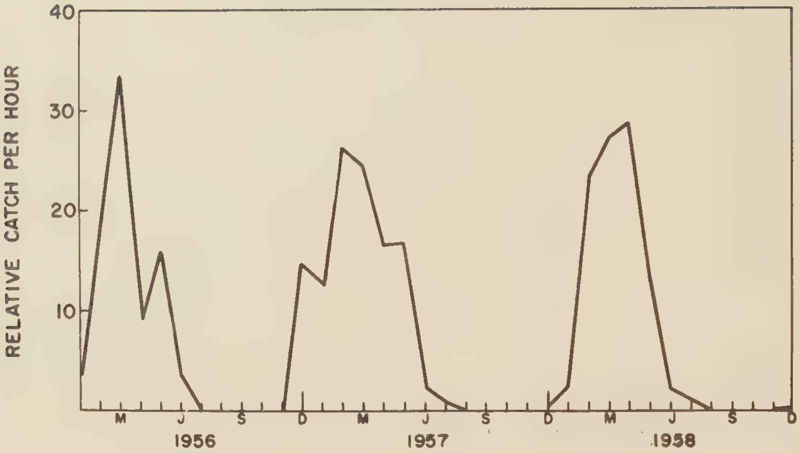


Fig. 13b. Yearly variation in seasonal changes of ocean pout abundance.

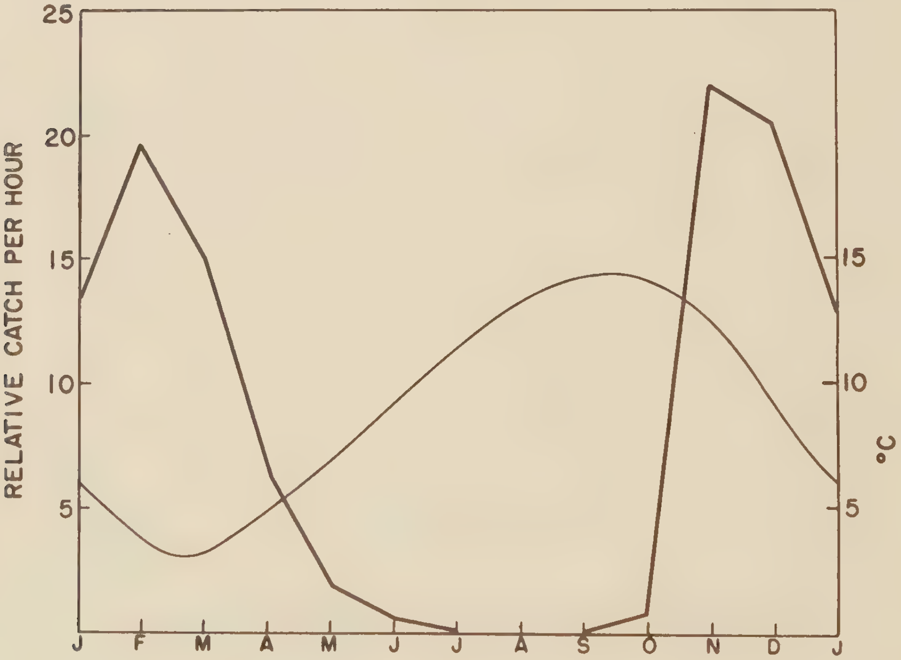


Fig. 14a. Seasonal changes in cod abundance on the Southwest Ground for the period 1956 through 1958, and average bottom temperature.

## DISCUSSION

The eight species discussed above illustrate the range of seasonal variations in relative abundance observed on the Southwest Ground. More than 25 species including skates and dogfish, were taken by the industrial trawl fishery on southern New England grounds and landed in quantities greater than 1,000 metric tons a year. With the exception of the winter flounder, skates, and dogfish, these others also show seasonal changes in abundance that one might hypothesize on the basis of winter distributional data. The winter flounder inhabits the bays and estuaries of this coast where it may be found during the colder months of the year. The seasonal changes observed on the Southwest Ground would lead one to believe that it was a fish with preferences similar to those of the red hake or angler. It is however actually moving offshore as temperatures increase. The

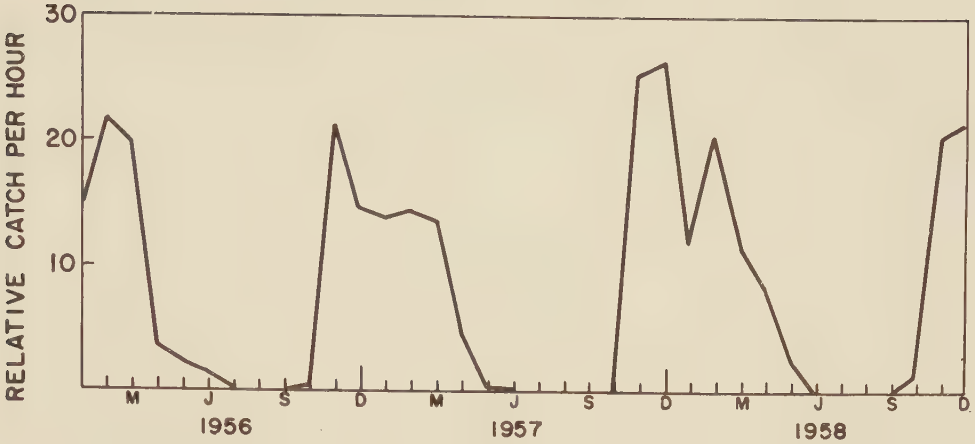


Fig. 14b. Yearly variation in seasonal changes of cod abundance.

analysis of the seasonal movements of skates and dogfish is complicated by differential movements on the parts of the two sexes. Such differential movement of the sexes may also be a factor in bony fish species but is easy to overlook since they are not so readily sexed.

The analysis of seasonal changes in abundance is further complicated by apparent changes in temperature preference on the part of different age groups. As was mentioned earlier, such appears to be the case with the silver hake and there are subtle indications in our data for other species that the phenomenon may be general. Size (or age) and sex are factors that should be considered in the experimental design of any future work.

Although the data presented here suggest that most, if not all, typical Middle Atlantic species tend to seek approximately the same temperature whether inshore in the summer or offshore in the winter, the question of availability has not been resolved. For most species the lack of fish in research vessel and commercial catches does reflect that the species has in fact left an area entirely. In others, as for example the ocean pout, the changes in seasonal abundance appear to represent a local shift to a different habitat that is not adequately sampled by the commercial fleet. The dramatic rise in catch/hour seen in the fluke at the time of overturn and that occurs within a 5 day period can only be interpreted as a change in availability whether due to aggregation or other behavioural change, or a shift in local habitat. Whatever the reason, it raises a question that must be resolved for each species. Most of the species discussed here show marked changes in availability between day and night. Fortunately, as mentioned earlier, the data presented in this paper may be presumed reasonably free of bias due to diurnal variations in abundance, since the Southwest Ground is seldom, if ever, fished after dark.

Most species arrive and depart in a relatively abrupt manner. Between arrival and departure the changes in abundance observed are more gradual and suggest that the fish are moving about the general area in a relatively passive manner with changes in relative abundance reflecting the general suitability of the area.

## REFERENCES

BUMPUS, D.F. 1957. Oceanographic observations, 1956, east coast of the United States. *U.S. Dept. Int., FWS, Spec. Sci. Rept. No. 233.*

BIGELOW, H.W. and W.C. SCHROEDER. 1953. Fishes of the Gulf of Maine. *Fish. Bull. U.S., 74.*

DAY, C.G. 1959*a*. Oceanographic observations, 1957, east coast of the United States. *U.S. Dept. Int., FWS, Spec. Sci. Rept. No. 282.*

1959*b*. Oceanographic observations, 1958, east coast of the United States. *U.S. Dept. Int., FWS, Spec. Sci. Rept. No. 318.*

EDWARDS, R. L. 1958. Species composition of industrial trawl landings in New England, 1957. *U.S. Dept. Int., FWS, Spec. Sci. Rept. No. 266.*

EDWARDS, R.L. and L. LAWDAY. 1960. Species composition of industrial trawl-fish landings in New England, 1958. *U. S. Dept. Int. FWS, Spec. Sci. Rept. No. 346.*

EDWARDS, R.L. and F.E. LUX. 1958. New England's industrial fishery. *U.S. Dept. Int., FWS, Comm. Fish Rev., 20 (5).*

EDWARDS, R.L., R. LIVINGSTONE and P.E. HAMER. 1961. Winter water temperatures and an annotated list of fishes—Nantucket Shoals to Cape Hatteras. *U.S. Dept. Int., FWS, Spec. Sci. Rept. No. 397.*

FISHER, R.A., A.S. CORBET and C.B. WILLIAMS. 1943. The relation between the number of individuals and the number of species in a random sample of an animal population. *Anim. Ecol.,* 12 (1).

OLSEN, Y.H. and D. MERRIMAN. 1946. The biology and economic importance of the ocean pout (*Macrozoarces americanus* Bloch and Schneider). *Bull. Bingham Oceanogr. Coll., 9 Art. 4.*

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# GEOLOGY AND BIOLOGY OF THE SEA FLOOR AS DEDUCED FROM SIMULTANEOUS PHOTOGRAPHS AND SAMPLES

BY K. O. EMERY, ARTHUR S. MERRILL, AND JAMES V. A. TRUMBULL

# GEOLOGY AND BIOLOGY OF THE SEA FLOOR AS DEDUCED FROM SIMULTANEOUS PHOTOGRAPHS AND SAMPLES[1]

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## ABSTRACT

During 1963, 260 paired photographs and large bottom samples were taken on the continental shelf and slope off northeastern United States. The photographs revealed surface characteristics of the sediments and natural attitudes of benthic animals; the samples retrieved specimens for geological and biological examination and identification.

Samples are the best source materials for making textural studies of sediments consisting mostly of sand, silt, or clay, but photographs are better than samples for bottoms too bouldery for proper sampling. Ripple marks and other surface irregularities revealed by the photographs supplement textural studies of the samples in deducing effects of wave movements and currents upon bottom materials.

For biological studies, the photographs yield much information on relationships of the benthic fauna to bottom materials, but they fail to provide useful data on biomasses. Biomasses and accurate taxonomic identifications are far better made upon samples. Thus, a combination of photographs and accompanying samples provides maximum information for biological as well as geological purposes.

## INTRODUCTION

Samples of the sea floor were taken at least as long ago as 450 B.C. when Herodotus (Carter 1958, Book II, Chap. 5) reported their use in navigation. Biological products such as pearl oysters, sponges, and edible shellfish were also taken in ancient times, but systematic studies of benthic biology appear to have begun only about 1750, by Marsigli and Donati (Murray and Hjort 1912). Samples recovered by dredging were and are so disturbed as to be unsuitable for interpreting many ecological relationships of different organisms with one another and with the substrate. Better information on natural conditions is given by direct observation by divers, but only in shallow water and without permanent records.

As an aid for benthic studies, Boutan (1900) made the first underwater pictures about 1893, but the technique remained largely unused until about 1940, when Ewing and his associates built a practical automatic underwater camera and used it for making photographs of general interest to geologists and biologists (Ewing, Vine, and Worzel 1946; Ewing et al. 1946). The same kind of camera was used by Shepard and Emery (1946) to examine the sea floor

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[1] Contribution No. 1508 from the Woods Hole Oceanographic Institution. Publication authorized by the Director, U.S. Geological Survey.

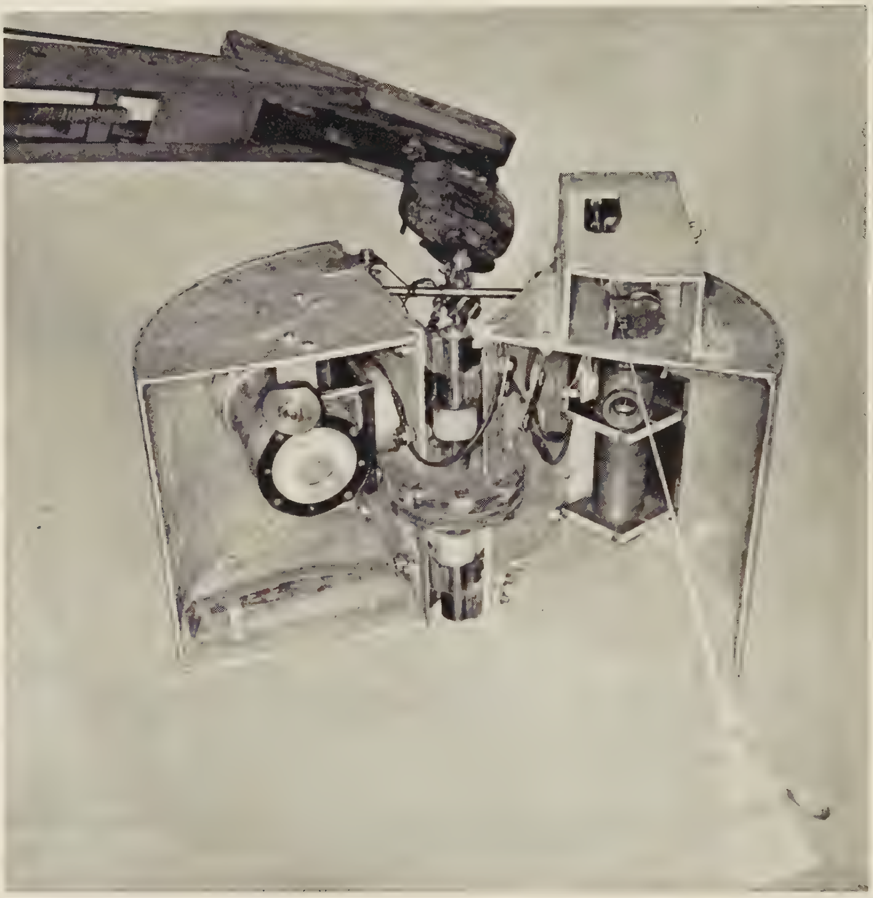


FIG. 1. Interior of Campbell grab sampler with camera and light source in place.

in various environments off California and Mexico. Later, the development of multiexposure cameras permitted an increase in coverage and in efficiency of photography for both geological and biological studies (Emery 1952; Edgerton and Hoadley 1955; Owen 1957; Shipek 1960; Laughton 1963). Many thousands of underwater photographs with hand-held cameras also have been taken for sport and for their strange beauty (Cousteau and Dugan 1963). In a brief review, Hahn (1950) predicted some additional future uses of underwater photographs in biology and geology; some of these have already become commonplace.

Except for the occasional use of a small coring tube attached to the camera frames and of a multiexposure camera attached to the cable above a dredge, bottom samples have rarely been obtained at the same sites that were photographed. Separate lowerings of camera and sampler cannot strike the same spot on the bottom when the ship is drifting in deep water or even reliably when the ship is anchored in shallow water. Several thousand large samples of the sea floor have been obtained in the same general regions that have been photographed, but the known patchy character of both sediments and benthic organisms prevents satisfactory correlation of samples with photographs. Unless specimens are at hand, biologists usually are reluctant to identify objects in photographs; thus, the photographs cannot be fully interpreted for data on distribution and ecological association of benthic organisms. Geologists likewise cannot always be certain from photographs that a smooth, silty surface of the sea floor does not conceal gravel immediately below the surface, nor can they consistently distinguish manganese nodules from sponges in photographs.

Improvement of both biological and geological interpretation of photographs and samples was permitted by a combined camera-sampler developed and tested by Menzies, Smith, and Emery (1963). The sampler was a heavy (250-kg, empty) clamshell designed and built by Alexander Campbell and used since 1954 aboard the University of Southern California's research vessel (Hartman 1955). Its jaws span an area of 0.56 $m^2$, and it can recover as much as 0.2 $m^3$ of bottom material. Within one jaw of the sampler was placed a Hasselblad camera in a watertight housing and within the other, a light source consisting of a flashbulb and a reflector. Contact of a trip weight with the bottom caused the light to flash and the camera shutter to open when the device was about 1 m above the bottom. On continued lowering, the sampler reached bottom, and the jaws closed when hoisting commenced. About 100 lowerings were made during 1961 and 1962 in order to compare photographs with samples. The comparison indicated that the photographs provide little information on subsurface fauna and show only the larger surface fauna. Frequent failure of prominent objects in the photographs to appear in the samples was attributed to a slight lateral movement of the device between photograph and closing.

Work was interrupted when Menzies and Emery left the University of Southern California. At the Woods Hole Oceanographic Institution, the present authors resumed work with the same sampler, but the camera was changed to a 35-mm Robot "Star" and the light source to a small strobotron unit. The device is illustrated in Fig. 1, and the fields of the photograph and the sample in Fig. 2. It is presently being used for studies of the surface materials and biology of the continental shelf and slope between Nova Scotia and the tip of Florida in a program conducted jointly by the Woods Hole Oceanographic Institution, the U.S. Geological Survey, and the Bureau of Commercial Fisheries. To date, the sampling and photographing have largely been completed between Nova Scotia and Delaware Bay. In this region, many large bottom samples had been obtained in an 18-km grid during 1957–1960 (Wigley 1961*a*), so that additional samples with the new equipment were needed only to fill gaps in the grid and to continue it to the southwest (Fig. 3). This work was done aboard *RV Gosnold*, a research ship of Woods Hole Oceanographic Institution.

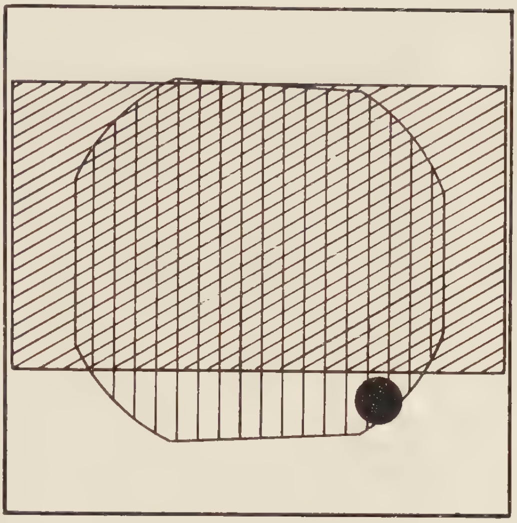


FIG. 2. Areas covered by sampler (diagonally crosshatched—0.56 $m^2$), by photograph (vertically crosshatched—0.48 $m^2$), and by trip weight (solid). The enclosing square is 1 m on each side.

The authors are indebted to D. M. Owen for design and construction of the new photographic unit and to R. L. Wigley and R. B. Theroux for aid in identification of organisms. Appreciation is also due all members of the geology group at the Woods Hole Oceanographic Institution who contributed many suggestions and who participated in the shipboard work, of which this paper is a partial result. Appreciation is due Edward Bradley, Elazar Uchupi, and R. L. Wigley for critical reading of the manuscript.

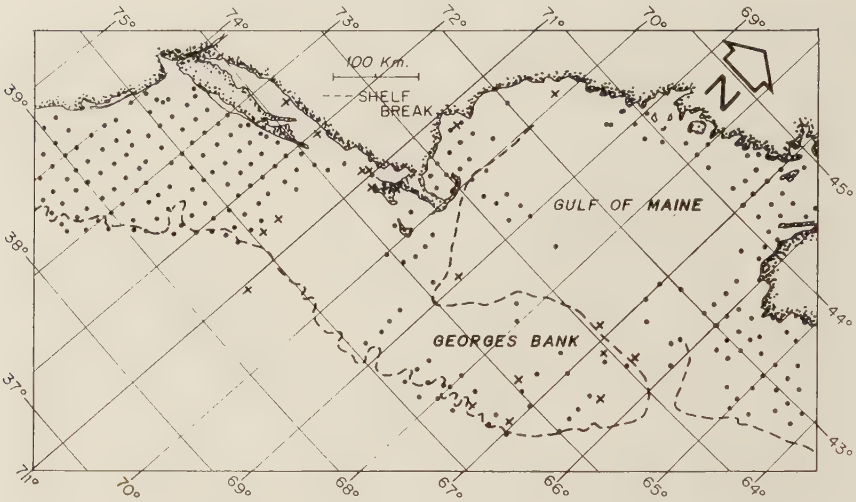

75°
74°
73°
72°
71°
70°
69°
100 Km.
SHELF BREAK
N
GULF OF MAINE
GEORGES BANK
39°
38°
37°
45°
44°
43°
71°
70°
69°
68°
67°
66°
65°
64°

FIG. 3. Positions of 260 stations (dots) where paired photographs and bottom samples were obtained with camera-sampler. Crosses show 19 earlier stations where pictures were taken with a simple camera by Ewing and his associates (1946). The dashed line within the Gulf of Maine is a topographic break at about the same depth as the shelf break.

## GEOLOGY

A simple chart of bottom sediments (Fig. 4) was constructed on the basis of visual inspection of the 800 large bottom samples from the regional grid. Bedrock occurs only locally, and it is largely covered with loose sediment. The continental shelf between Delaware Bay and Cape Cod, its eastward extension as Georges Bank, and the continental shelf off Nova Scotia are floored chiefly by sand and by gravel and sand with irregular patches of sandy silt. In a general way, this sediment exhibits a progressive increase in grain size from southwest to northeast. The patterns off New Jersey and New York resemble those

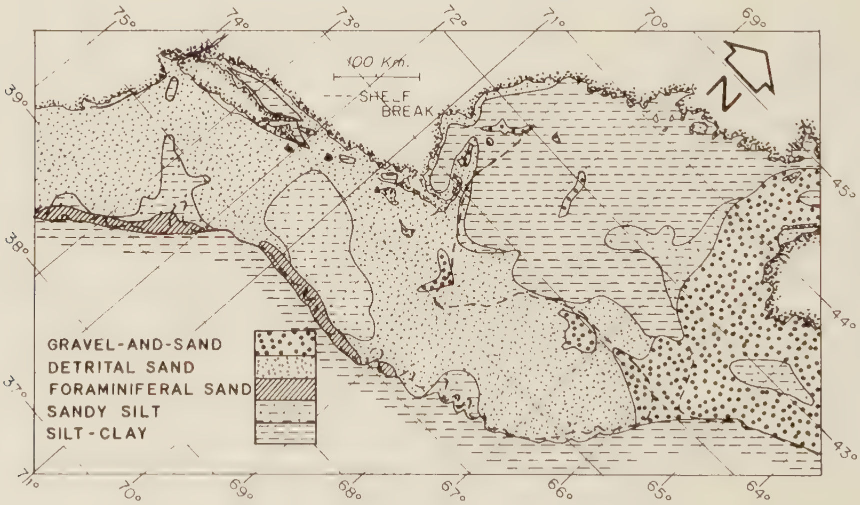

75°
74°
73°
72°
71°
70°
69°
100 Km.
SHELF BREAK
N
GRAVEL-AND-SAND
DETRITAL SAND
FORAMINIFERAL SAND
SANDY SILT
SILT-CLAY
39°
38°
37°
45°
44°
43°
71°
70°
69°
68°
67°
66°
65°
64°

FIG. 4. Generalized bottom sediment chart constructed from visual inspection of 800 samples taken on an approximate 18-km grid throughout most of the area.

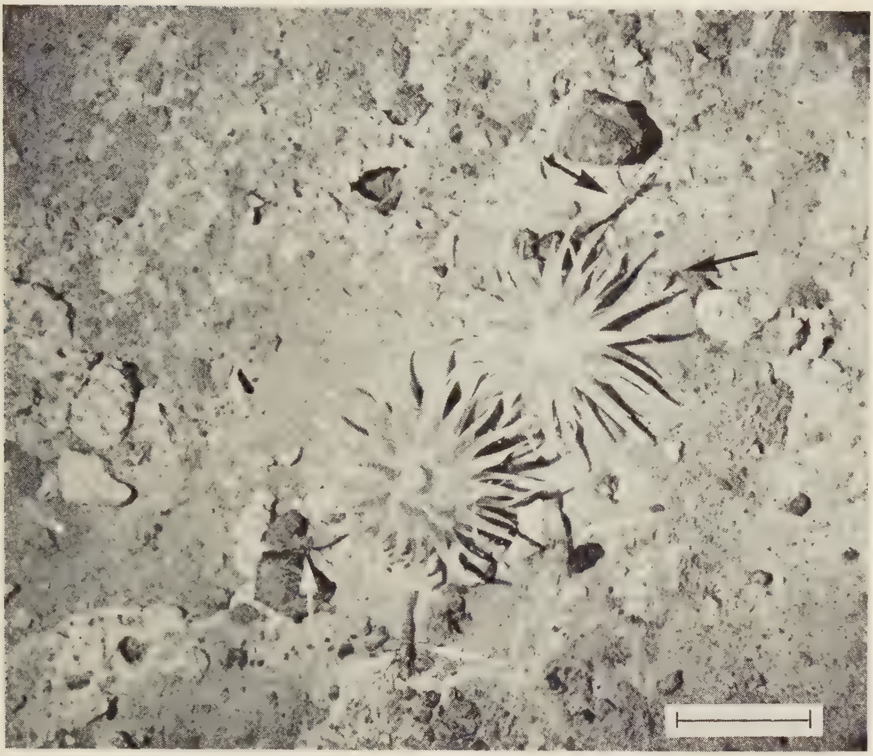


FIG. 5. Photograph at Station 1061 southwest of Georges Bank, off Massachusetts (40°11.0′ N lat, 68°29.5′ W long, 507 m). Bottom consists of blue clay, green sand, and angular pebbles to 6 cm diameter (probably glacial till). Around and under the two large sea anemones, *Bolocera*, are several partly camouflaged caridean shrimp (Decapoda) indicated by arrows. Scale bar is 10 cm long.

mapped by Shepard and Cohee (1936) on the basis of much smaller samples; the ones on Georges Bank also are similar to those drawn by Shepard (1939) mostly from chart notations and by Wigley (1961*a*) from many of the same samples used in this program.

Protected waters in certain areas of the continental shelf (the Gulf of Maine, Long Island Sound, and several small bays) have sediments consisting mostly of silty clay and clayey silt, but sand and gravel are common near shore, and gravel and boulders of glacial or ice-rafted origin dominate on the tops of banks and ridges. Thus, the Gulf of Maine has both finer and coarser sediments than the rest of the continental shelf. The shelf break southwest of Georges bank has a narrow belt of green sand composed largely of foraminifera and glauconite. Farther seaward on the continental slope and continental rise, the sediments consist chiefly of green silty clay.

Photographs, in black and white and some in color, accompany 260 of the 800 bottom samples. Black-and-white film has the advantage of ease of processing aboard ship to detect malfunctions and to correct errors in exposure. Color film permits the recognition of certain small animals and of encrustations such as calcareous algae that blend into the background in black-and-white pictures. The color film also provides approximately correct colors of plants, animals, rocks, and sediments, in contrast to the bleached appearance after preservation or drying.

Stations having gravel or boulder bottoms sometimes required several lowerings before a satisfactory sample could be obtained, but each lowering produced a photograph; thus, an additional 65 photo-

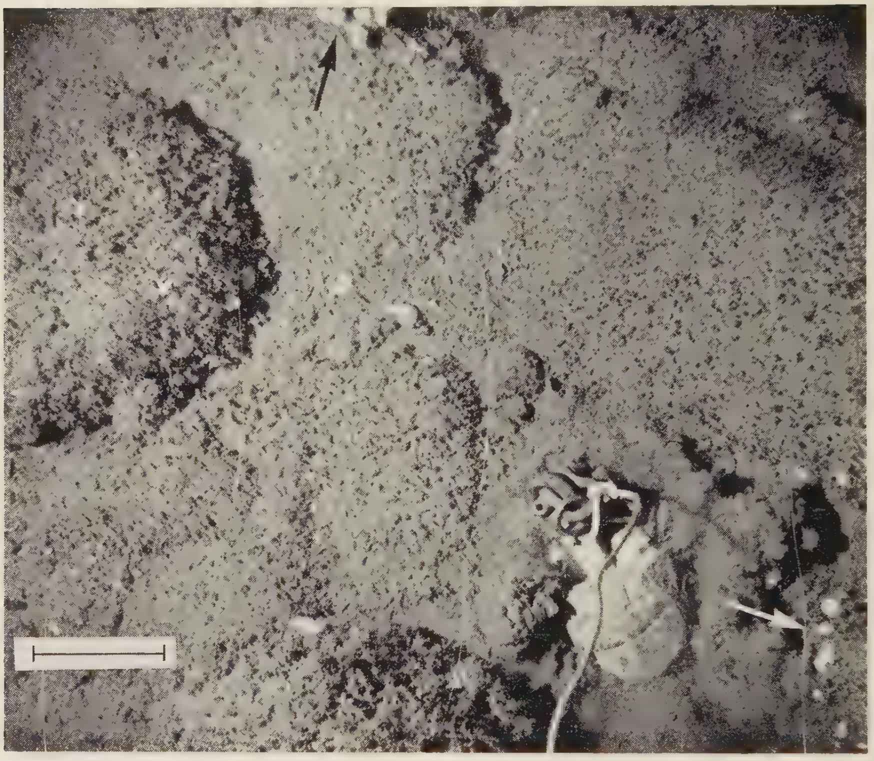


FIG. 6. Photograph at Station 1200 off Boston (42°29.8′ N lat, 70°44.7′ W long, 43 m). Boulders to 70 cm diameter are covered by many small attached organisms and by a film of clayey silt. The entire surface is dotted with projecting annelid worm tubes. A number of brachiopods, *Terebratulina* (arrows), are attached to the rocks. Scale bar is 10 cm long.

graphs are at hand. At a given station, these extra photographs show close similarities in the nature of the bottom but differences in percentage composition or other details. At some early stations, samples were taken but the camera failed; resampling was impractical because the failure was discovered only much later when the film was developed and individual frames were identified. Nevertheless, the available paired photographs and samples provide much information supplementary to that from samples alone, as illustrated by Figs. 5 through 16.

A type of bedrock is illustrated by Fig. 5. Soft lumps of blue clay found in this sample are revealed to be coherent loose masses on the bottom, and angular pebbles are seen to be embedded in the clay. The pebbly clay is believed to be glacial till deposited by a tongue of glacial ice that protruded across the base of Georges Bank through a shallow valley shown on charts as Great South Channel. Loose sand present as thin discontinuous patches probably had a different source.

Most of the boulders and gravel in the region were deposited by glaciers or melting icebergs. Photographs within the Gulf of Maine show that these coarse materials are mostly angular and poorly sorted (Fig. 6). Locally, they are covered, perhaps temporarily, by a film of silt or clay (Fig. 6). Within some relatively flat-floored basins, the boulders are buried under silt or clay except at the margins where they may project above a thinner part of the blanket and form small sites for attachment of encrusting organisms (Fig. 7). Boulders and gravels on the continental shelf and

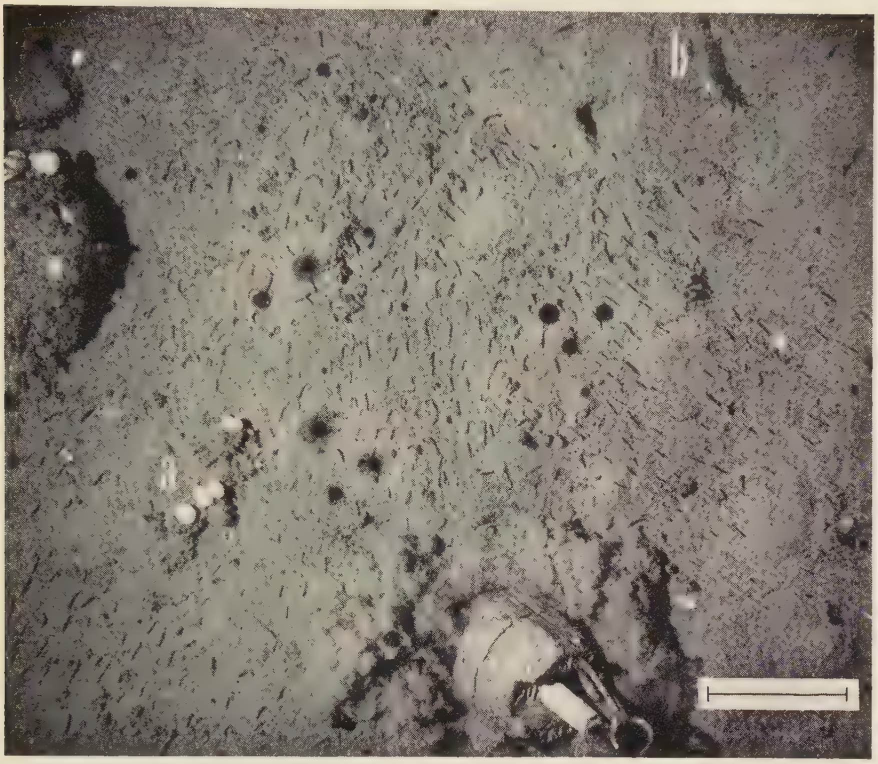


FIG. 7. Photograph at Station 1235 south of Nova Scotia (43°10.4′ N lat, 65°15.8′ W long, 144 m). Rounded boulders to 25 cm diameter protrude above a blanket of brown silty sand. Attached to the boulders are clumps of brachiopods, *Terebratulina* (a). Atop the silty sand is a shrimp (Pandalidae) (b). Through the sediment project tubes of many annelid worms (probably Maldanidae and Terebellidae, judging from examination of the sample). The larger holes were made by an unknown burrowing animal. Scale bar is 10 cm long.

Georges Bank are mostly subround to round (Fig. 8), presumably as a result of action of outwash streams or postglacial wave movement. Where they are exposed to vigorous currents on the continental shelf, the boulders and gravels are clean (Fig. 8).

Shells are abundant (Fig. 9) on the tops of hills or banks where the rate of deposition of new detrital material is slow, and they locally even constitute a shell hash, or near-coquina (Fig. 10). Where currents are swift, as on parts of Georges Bank, finer materials have been swept away, leaving a residual pavement of well-sorted and well-rounded pebbles (Fig. 11). Locally, the pavement is covered or interrupted by a thin (Fig. 12) to very thick (Fig. 13) layer of wave- or current-rippled clean sand. Elsewhere on the continental shelf, particularly deeper than about 25 m, the sediments consist of silty fine- and medium-grained sand or sandy silt that is unrippled and inhabited by many animals whose burrows, trails, and refuse heaps create intricate patterns (Figs. 14, 15) similar to those described from recent and ancient sediments by Seilacher (1954). The blanket of silty clay in quiet deeper waters of the Gulf of Maine and elsewhere may be even more richly marked by benthic animals (Fig. 16).

Comparisons of photographs and samples led to the conclusion that for some purposes photographs are superior and for others samples are better. Only huge samples are adequate for determining the per-

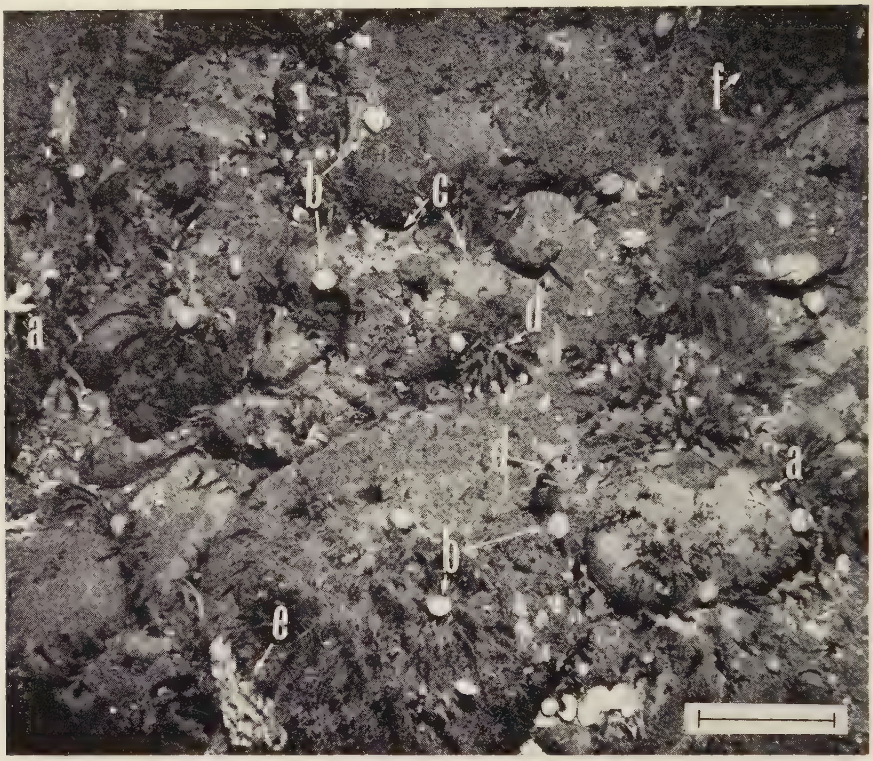


FIG. 8. Photograph at Station 1246 south of Nova Scotia (43°30.0′ N lat, 65° 00.0′ W long, 112 m). Bottom consists of round boulders to 45 cm diameter with gravel and brown coarse-grained sand in interstices. Attached to the boulders are many animals including two starfish, *Leptasterias* (a), about 40 brachiopods, *Terebratulina* (b), perhaps 25 bryozoan colonies both encrusting (c) and branching (d), and some sponge (Porifera) (e). Protruding from crevices and from beneath boulders about 50 annelid worm tubes (Sabellidae) (f) can be seen. Scale bar is 10 cm long.

centage of total sediment consisting of boulders; it is just such kinds of bottom where sampling is most difficult. A photograph is probably more useful for estimating this percentage. The plot of Fig. 17, based on photographs, shows the greatest percentage of boulders and gravel (distinguishable as coarser than about 4 mm on the photographs) to be off Nova Scotia, on eastern Georges Bank, and along the shores of Massachusetts, in accordance with the distributions of Fig. 4 based upon samples. In general, the maximum diameters of boulders and gravels are also greatest where these materials are most abundant.

Maximum diameters of coarse materials measured on some photographs correspond with measurements of those recovered in the samples, but a wide scatter of points is evident in Fig. 18. This scatter is partly explained by the fact that on a bottom consisting mostly of boulders and gravel the sampler cannot easily dig in and recover a sample, and in these cases the maximum diameter of boulder or cobble in the sample is commonly smaller than in the photograph. Conversely, where the bottom is mostly sand, silt, or clay with less than 50% of the area consisting of pebble or larger sizes, the sampler can dig out and retrieve larger pieces buried beneath the fine sediments. A similar relationship is shown by a comparison of burrowing organisms in the photographs and samples. Starfish and particularly sand dollars, *Echinarachnius parma*, are present in many photographs of

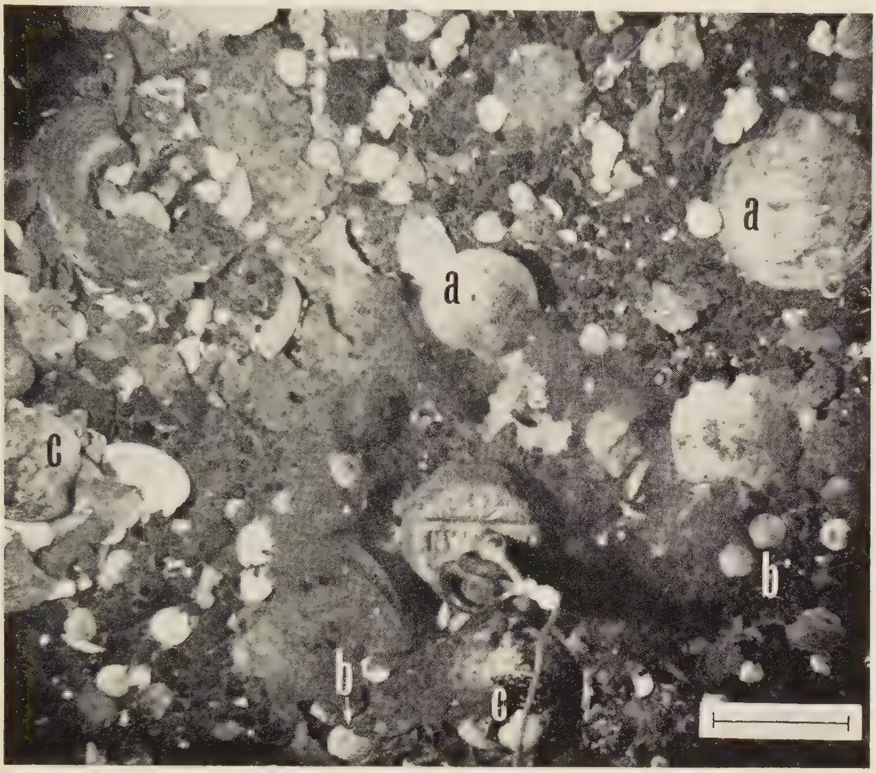


FIG. 9. Photograph at Station 1165 near entrance of Bay of Fundy (44°08.6′ N lat, 66°28.8′ W long, 87 m). Angular to rounded gravel to 7 cm diameter and medium- to coarse-grained sand contains many large corroded shells. The dominant shells include the following pelecypods: *Placopecten magellanicus* (a), *Venericardia borealis* (b), and *Arctica islandica* (c). Scale bar is 10 cm long.

soft bottom (Fig. 14), but they are far more common in the samples (Fig. 19), even when allowance is made for the slightly greater area of bottom covered by the sampler as compared with the photograph (Fig. 2).

Information about currents can also be deduced from the photographs and samples. As shown by Fig. 20, many stations near Boston (southwest side of Gulf of Maine) have boulders covered by a film of silt (Fig. 6). Fine-grained sediment probably contributed by the local rivers may be deposited on the boulders until swept away by marine currents, perhaps seasonally. Somewhat similar mantling of boulders by silt occurs off Nova Scotia (northeast side of Gulf of Maine). At other stations, particularly ones in shallow depths and commonly in association with ripple marks, the water was noticeably turbid in the photographs, presumably because of wave turbulence. Many photographs show symmetrical ripple marks indicative of wave activity (Fig. 12); others have asymmetrical ripples (Fig. 13) that indicate movement by currents. Features such as scour marks, leaning algae, and leaning worm tubes also indicate water movement. A compass mounted in the camera trip weight (Fig. 12) serves to determine orientation of the water movements, except in early lowerings made before the compass was installed, and in later ones where the trip weight happened to fall sideways or to be outside the field of view. A plot (Fig. 21) of all bottom indicators showing a prevailing direction of water movement indicates a curious and doubtlessly coincidental segregation of wave ripples in the southwestern part of

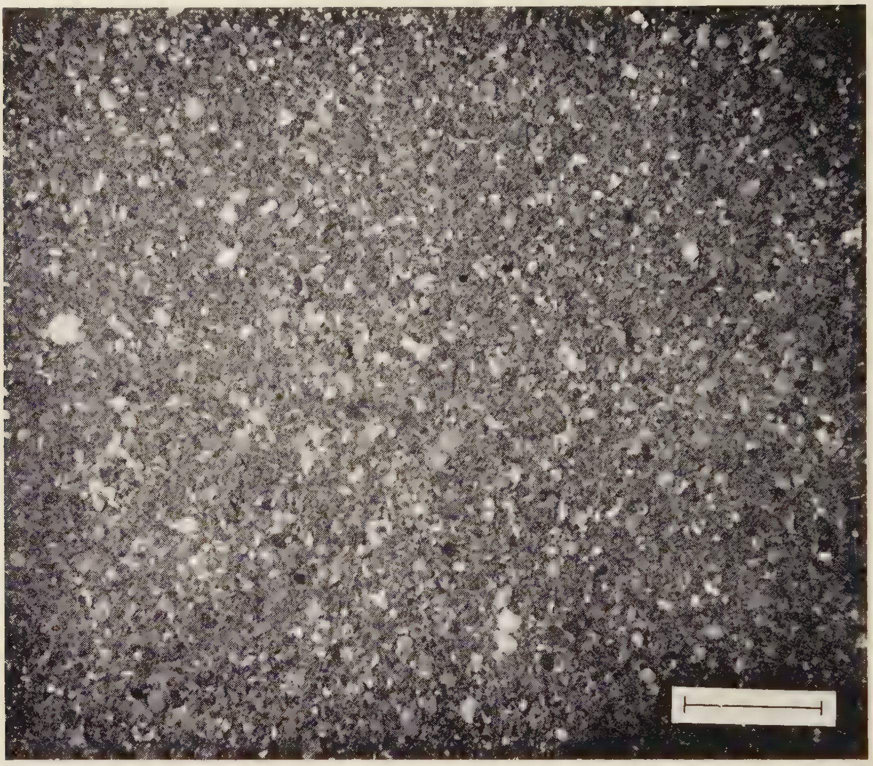


FIG. 10. Photograph at Station 1174 near entrance of Bay of Fundy (44°28.7′ N lat, 67°01.5′ W long, 57 m). Bottom sediment is entirely shell hash (broken shells). No living or freshly dead animals can be identified in the photograph. Scale bar is 10 cm long.

the region and of current marks in the northeastern part. Waves are inferred as chiefly moving landward from the southeast. No interpretation is made of the current ripples and other marks on Georges Bank, because ebb and flood tidal currents of 3 km/hr are known to be oppositely directed in this region (Haight 1942; Stewart and Jordan 1964).

Photographs and samples together show that the highest percentages of shells occur on sand rather than on silty clay bottoms. Geological experience suggests that the reverse should be true, because greater losses of calcium carbonate during diagenesis and later history are to be expected in the more pervious sands. The broken condition of most shells found in the sediments is due to solution, activity of marine boring organisms, and mechanical crushing by predators and by water turbulence. The effectiveness of comminution is illustrated by the presence of more than 25 times as many living specimens of the sand dollar as major parts of dead ones.

Many photographs show attached valves (clappers) as well as separated ones of the surf clam, *Spisula solidissima,* and of the ocean quahog, *Arctica islandica,* atop a sand or silt substrate. Both species live just below the sediment surface. To a geologist, the presence of the valves atop the sediment suggests active erosion of the sediment leading to residual concentration of the valves. However, close examination of the photographs reveals that 62% of the valves are concave upward; active currents should have left nearly all convex upward (Shrock 1948, p. 305–320). The paradox may be resolved by observations in laboratory tanks which show that, as death approaches, the animal relaxes, and its valves

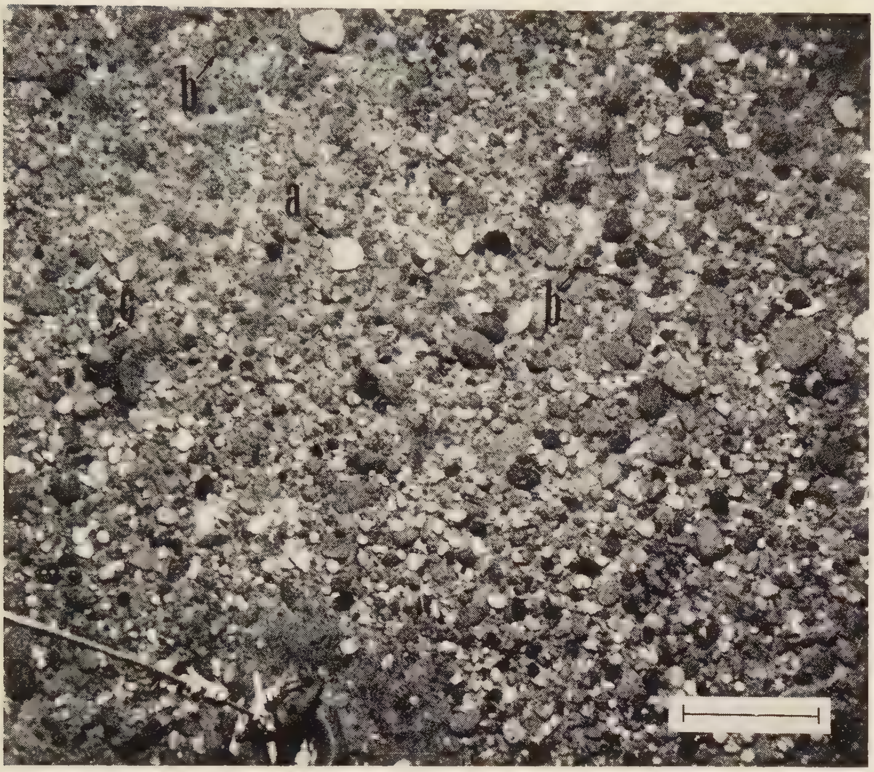


FIG. 11. Photograph at Station 1129 atop Georges Bank (41°50.8′ N lat, 66°45.4′ W long, 65 m). Bottom is covered by well-sorted and rounded gravel to 6 cm diameter with brown coarse-grained sand in interstices. Easily seen among the pebbles is a valve of the pelecypod *Astarte castanea* (a). Well camouflaged are the tubes of a number of tube-dwelling coelenterates, *Cerianthus borealis* (b), and a hermit crab, *Pagurus,* in a *Buccinum* (?) shell (c). Scale bar is 10 cm long.

gape farther apart until they lie on the bottom in the position of an open book. After the two valves separate, there is thus a tendency for each to remain in a concave upward position.

### BIOLOGY

Total volume of sediment and rock at each station ranged from 3 to 100 liters and averaged 19 liters. After removal of about a liter of original material for sediment and other subsamples, the remainder of the sample was screened on a 1-mm sieve aboard ship. Material that passed through the sieve was discarded, and all sediment and organisms that were retained by the sieve were preserved in formalin. On receipt of the preserved material at the Bureau of Commercial Fisheries, each sample was sorted into convenient major groups of animals (phylum, class, or order); these were counted and weighed after excess water was blotted away; the specimens were then transferred to alcohol for later specific classification by specialists. The counts and weighings supported earlier work by Wigley (1961*b*) and others in exhibiting a dependence upon the nature of the substrate. In order to portray this relationship, a number of stations having good samples and equally good photographs were selected as typical of each kind of substrate. The eight substrates of this classification are as follows:

Boulders largely buried in sandy silt and commonly covered by a thin film of sandy silt (Figs. 6, 7).

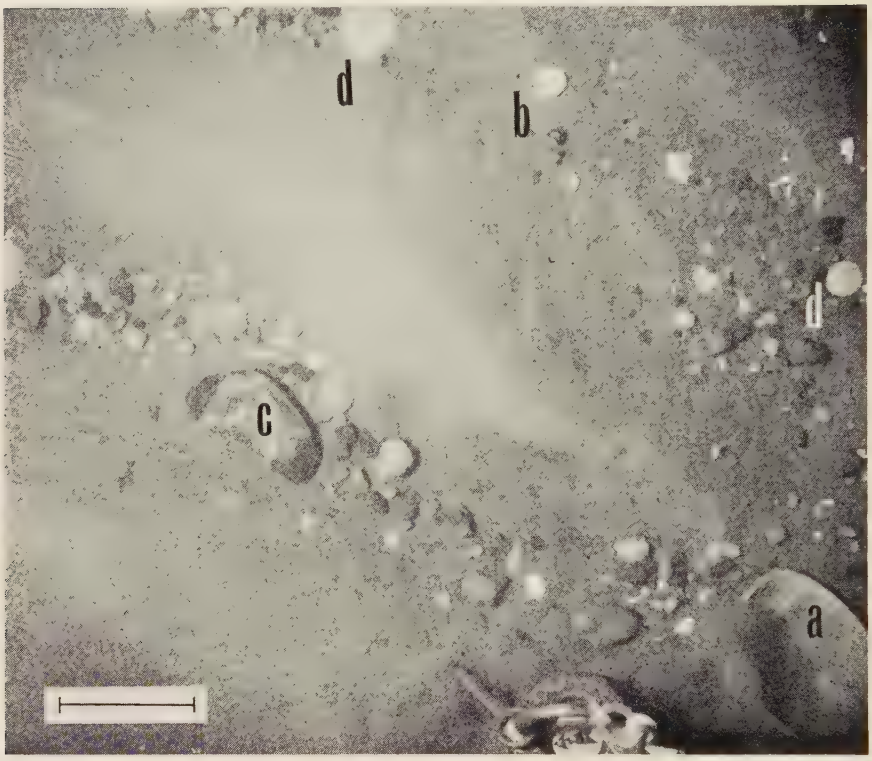


FIG. 12. Photograph at Station 1394 a short distance south of Long Island (40° 43.9′ N lat, 72°44.1′ W long, 23 m). Ripples of gray coarse-grained sand lie atop a pavement of rounded gravel up to 3 cm in diameter. Note the compass in the trip weight; it orients the photograph for making plots of the direction of water motion (Fig. 21). In the ripple troughs are dead shells and tests of the pelecypods *Spisula solidissima* (a), *Astarte undata* (b), and *Crassostrea virginica* (c), and the echinoderm *Echinarachnius parma* (d). Scale bar is 10 cm long.

Gravel or boulders with a small percentage of coarse sand in the interstices (Fig. 8).
Shelly sand, locally silty (Fig. 9).
Shell hash (broken shells) with almost no detrital sediment (Fig. 10).
Clean sand with rounded gravel (Fig. 11).
Clean detrital sand (Figs. 13, 14).
Sandy silt (Fig. 15).
Fine-grained sediment, silty clay, or clayey silt (Fig. 16).

The biological results at 37 stations grouped according to substrate are given in Tables 1 and 2. The total fauna ranged from 43 to 4,883 specimens per m². Averages for each kind of substrate (Table 3) indicate that gravel or boulders and sand had the highest number of specimens and shell hash the lowest. At most stations, the benthic fauna was dominated by either crustaceans or annelids, but at some stations echinoderms, mollusks, or bryozoans were dominant. These dominant groups ranged from 16 to 90% of the total number of specimens and averaged about 52%. When expressed in terms of weight, the biomass ranged from 2 to 1,057 g/m², with the greatest biomass again in boulders or gravel and sand and the lowest again in shell hash. In general, however, the number of specimens and the biomass do not exhibit a parallel relationship, because some faunas consisted of many small animals (annelids in silt clay) and others consisted of fewer but heavier animals (large

TABLE 1. *Total fauna and dominant group at selected stations of various bottom materials**

| Bottom type | *Gosnold* stations | Total no. specimens | No. specimens in dominant group | | | | | Ratio dominant to total no. specimens |
|---|---|---|---|---|---|---|---|---|
| | | | Annelids | Mollusks | Bryozoans | Crustaceans | Echinoderms | |
| Boulders in sandy silt | 1175 | 643 | 199 | | | | | 0.31 |
| | 1177 | 1,335 | 726 | | | | | 0.54 |
| | 1200 | 961 | 518 | | | | | 0.54 |
| | 1224 | 335 | 110 | | | | | 0.33 |
| | 1235 | 342 | 121 | | | | | 0.35 |
| Gravel or boulders and sand | 1103 | 4,883 | | | | 2,238 | | 0.46 |
| | 1148 | 100 | 52 | | | | | 0.52 |
| | 1150 | 103 | | | | | 29 | 0.28 |
| | 1158 | 1,360 | 406 | | | | | 0.30 |
| | 1246 | 260 | | | 142 | | | 0.55 |
| Shelly sand | 1165 | 347 | | | | 194 | | 0.56 |
| | 1216 | 139 | 59 | | | | | 0.42 |
| | 1241 | 545 | | | | 425 | | 0.78 |
| | 1275 | 210 | | | | 167 | | 0.80 |
| | 1277 | 4,297 | | | | 3,695 | | 0.86 |
| | 1339 | 618 | | | | 265 | | 0.43 |
| Shell hash | 1174 | 114 | 64 | | | | | 0.56 |
| Sand and gravel | 1129 | 377 | | | | 110 | | 0.29 |
| | 1133 | 93 | 43 | | | | | 0.46 |
| | 1134 | 251 | | | | | 39 | 0.16 |
| | 1140 | 278 | 134 | | | | | 0.48 |
| | 1291 | 837 | | | | 662 | | 0.79 |
| Sand | 1052 | 43 | | 21 | | | | 0.49 |
| | 1060 | 840 | | | | 716 | | 0.85 |
| | 1157 | 310 | | | | 192 | | 0.62 |
| | 1196 | 265 | 228 | | | | | 0.86 |
| | 1221 | 680 | | | | 486 | | 0.72 |
| Sandy silt | 1164 | 262 | 78 | | | | | 0.30 |
| | 1166 | 1,381 | 885 | | | | | 0.64 |
| | 1231 | 82 | 34 | | | | | 0.42 |
| | 1309 | 516 | | | | 329 | | 0.64 |
| | 1322 | 2,172 | | | | 1,962 | | 0.90 |
| Silt clay | 1173 | 571 | | | | 252 | | 0.44 |
| | 1188 | 61 | | 32 | | | | 0.52 |
| | 1212 | 618 | 358 | | | | | 0.58 |
| | 1234 | 255 | 194 | | | | | 0.76 |
| | 1335 | 219 | 77 | | | | | 0.35 |

* Data expressed in number of specimens per m².

pelecypods such as *Arctica islandica*) in sandy silt. The fortuitous occurrence of one or a few large organisms in a sample caused the station-to-station dominancy to vary more when evaluated on a weight ratio to total fauna than on a number ratio. By weight, the dominant groups averaged 65% of the total biomass.

The average total biomass of the 37 samples was 156 g/m², exactly the same as the biomass obtained by Wigley (1961*b*) for 161 samples from Georges Bank. When the biomasses of the different kinds of substrate were weighted according to the percentage area covered by these substrates, the biomass for the entire area of Fig. 4 amounted to about 120 g/m². This figure is lower than the average of 300 g/m² for the mainland shelf of southern California, which has similar substrates (Emery 1960, p. 178). It is also somewhat lower than the world average biomass of the 0–200-m zone reported by Zenkevitch, Barsanova, and Belyaev (1960) and by Vinogradova (1962) as 200 g/m².

Surface fauna can be defined from the viewpoint of habitat as those organisms that live atop the substrate, in contrast to

TABLE 2. *Total fauna and dominant group at selected stations of various bottom materials**

| Bottom type | *Gosnold* stations | Total wt (g) | Weight of dominant group (g) | | | | | | | Ratio dominant to total wt |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | Poriferans | Annelids | Brachiopods | Mollusks | Bryozoans | Crustaceans | Echinoderms | |
| Boulders in sandy silt | 1175 | 16 | | 7 | | | | | | 0.45 |
| | 1177 | 439 | 234 | | | | | | | 0.53 |
| | 1200 | 147 | | 74 | | | | | | 0.50 |
| | 1224 | 46 | | | 21 | | | | | 0.45 |
| | 1235 | 113 | | | 51 | | | | | 0.45 |
| Gravel or boulders and sand | 1103 | 1,046 | | | | | | 985 | | 0.94 |
| | 1148 | 16 | | | | | | 12 | | 0.76 |
| | 1150 | 49 | | | | 33 | | | | 0.68 |
| | 1158 | 886 | | | | | 497 | | | 0.56 |
| | 1246 | 22 | | | | | 14 | | | 0.62 |
| Shelly sand | 1165 | 7 | | 3 | | | | | | 0.45 |
| | 1216 | 5 | | 1 | | | | | | 0.21 |
| | 1241 | 11 | | | | | | 9 | | 0.81 |
| | 1275 | 96 | | | | 87 | | | | 0.91 |
| | 1277 | 757 | | | | 707 | | | | 0.94 |
| | 1339 | 148 | | | | 137 | | | | 0.93 |
| Shell hash | 1174 | 9 | | 6 | | | | | | 0.67 |
| Sand and gravel | 1129 | 50 | | | | 19 | | | | 0.38 |
| | 1133 | 6 | | 3 | | | | | | 0.55 |
| | 1134 | 17 | | 5 | | | | | | 0.31 |
| | 1140 | 33 | 10 | | | | | | | 0.30 |
| | 1291 | 162 | | | | | | | 153 | 0.94 |
| Sand | 1052 | 2 | | | | 2 | | | | 0.78 |
| | 1060 | 16 | | | | | | | 8 | 0.47 |
| | 1157 | 20 | | 8 | | | | | | 0.43 |
| | 1196 | 3 | | 2 | | | | | | 0.67 |
| | 1221 | 261 | | | | 248 | | | | 0.95 |
| Sandy silt | 1164 | 300 | | | | 274 | | | | 0.91 |
| | 1166 | 1,057 | | | | 647 | | | | 0.61 |
| | 1231 | 24 | | | | | | | 18 | 0.75 |
| | 1309 | 308 | | | | 297 | | | | 0.97 |
| | 1322 | 159 | | | | 142 | | | | 0.90 |
| Silt clay | 1173 | 32 | | | | 11 | | | | 0.33 |
| | 1188 | 18 | | | | | | | 17 | 0.97 |
| | 1212 | 38 | | 28 | | | | | | 0.73 |
| | 1234 | 21 | | 19 | | | | | | 0.89 |
| | 1335 | 15 | | 6 | | | | | | 0.38 |

* Data expressed in g per $m^2$.

TABLE 3. *Dominant groups in total fauna*

| Bottom type | Total fauna | | Dominant group | | Ratio of dominant group to total fauna | |
|---|---|---|---|---|---|---|
| | No. specimens | Weight (g) | No. specimens | Weight (g) | No. specimens | Weight (g) |
| Boulders in sandy silt | 723 | 152 | 335 | 77 | 0.41 | 0.48 |
| Gravel or boulders and sand | 1,541 | 404 | 573 | 308 | 0.33 | 0.71 |
| Shelly sand | 1,026 | 171 | 801 | 158 | 0.64 | 0.73 |
| Shell hash | 114 | 9 | 64 | 6 | 0.56 | 0.67 |
| Sand and gravel | 367 | 54 | 198 | 38 | 0.44 | 0.50 |
| Sand | 428 | 61 | 329 | 54 | 0.71 | 0.66 |
| Sandy silt | 883 | 370 | 658 | 276 | 0.58 | 0.83 |
| Silt clay | 345 | 25 | 183 | 16 | 0.53 | 0.66 |
| Overall average | 678 | 156 | 373 | 117 | 0.52 | 0.65 |

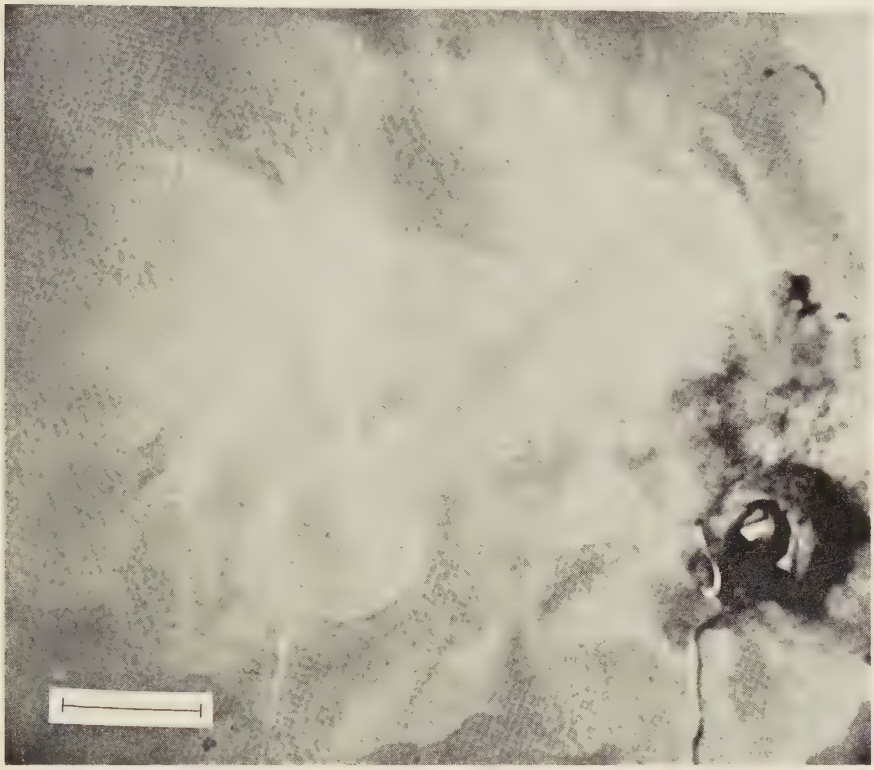


FIG. 13. Photograph at Station 1221, central Georges Bank (41°30.3′ N lat, 67°00.6′ W long, 66 m). Gray medium sand exhibits many irregularities probably initiated by burrowing organisms and modified by currents into ripple marks. Scale bar is 10 cm long.

subsurface fauna, which live beneath the surface. Organisms encrusting rocks are obviously surface fauna. However, some annelid worms, normally considered to be subsurface fauna, construct tubes that project above the bottom and thus are visible on photographs. When making counts of visible organisms, an adjustment was made according to the ratio of empty and occupied worm tubes in the accompanying

TABLE 4. *Surface fauna and subsurface fauna in samples*

| Bottom type | Total fauna | | Subsurface fauna | | Surface fauna | | Ratio of surface fauna to total fauna | |
|---|---|---|---|---|---|---|---|---|
| | No. specimens | Weight (g) | No. specimens | Weight (g) | No. specimens | Weight (g) | No. specimens | Weight (g) |
| Boulders in sandy silt | 723 | 152 | 362 | 22 | 361 | 130 | 0.50 | 0.86 |
| Gravel or boulders and sand | 1,541 | 404 | 661 | 17 | 880 | 387 | 0.57 | 0.96 |
| Shelly sand | 1,026 | 171 | 156 | 121 | 870 | 50 | 0.85 | 0.29 |
| Shell hash | 114 | 9 | 46 | 1 | 68 | 8 | 0.60 | 0.85 |
| Sand and gravel | 367 | 54 | 85 | 5 | 282 | 49 | 0.77 | 0.91 |
| Sand | 428 | 61 | 47 | 3 | 381 | 58 | 0.89 | 0.95 |
| Sandy silt | 883 | 370 | 260 | 67 | 623 | 303 | 0.71 | 0.82 |
| Silt clay | 345 | 25 | 173 | 14 | 172 | 11 | 0.50 | 0.43 |
| Overall average | 678 | 156 | 221 | 31 | 455 | 124 | 0.67 | 0.76 |

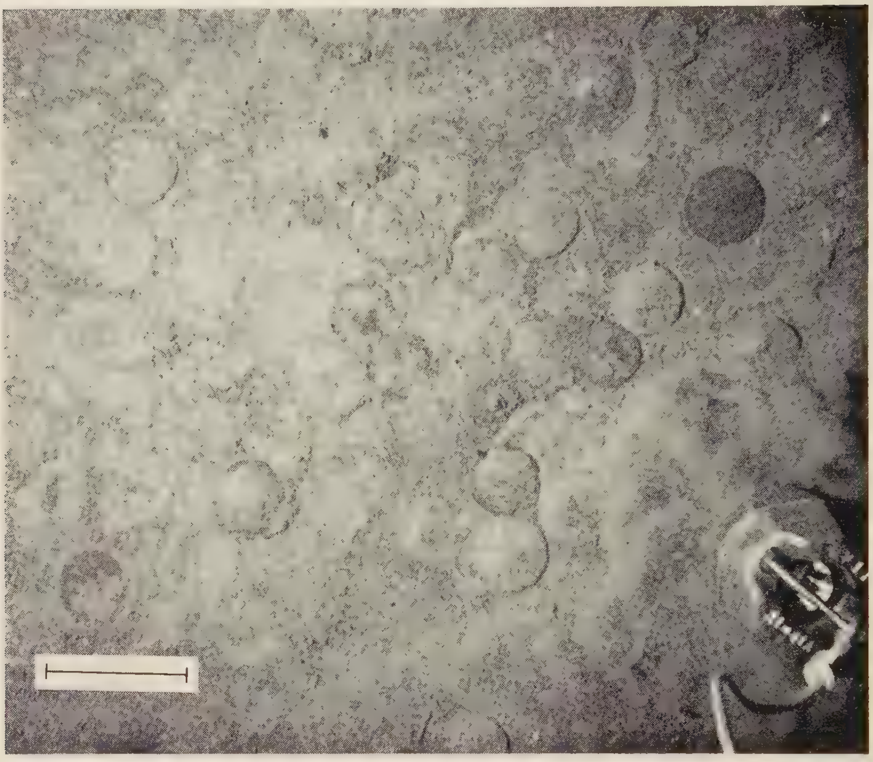


FIG. 14. Photograph at Station 1343 off New Jersey (39°10.9′ N lat, 73°45.0′ W long, 38 m). Sediments are olive medium-grained sand containing many living sand dollars, *Echinarachnius parma.* Most specimens are partially buried in the sand. Scale bar is 10 cm long.

sample. Conversely, many other samples contained hundreds of amphipods ordinarily considered as surface fauna but too small to be seen in the photographs. For purpose of photographic interpretation, the term surface fauna as used in this study was defined as consisting of organisms that live on the bottom or have portions of their bodies or tube linings exposed above the bottom. Using this definition, the total fauna of Tables 1 and 2 was subdivided into subsurface fauna and surface fauna. The results (Table 4) reveal that the averages for the surface fauna on the eight kinds of substrate range from 50 to 89% of total fauna in terms of number of specimens, and from 29 to 96% in terms of weight. The number and weight ratios again are more or less independent of each other owing to the presence of numerous small specimens in some samples and of fewer but heavier ones in others. In general, however, the surface fauna may be considered as constituting two-thirds to three-quarters of the total fauna.

Counts of organisms on the photographs (that is, surface fauna) at each station provide data for averages for each kind of substrate (Table 5). The average, expressed in percentage of surface fauna that was seen in the photographs, ranges from 0 to 94, and averages 26 for all eight kinds of substrate. The photographs most accurately reveal the surface fauna in areas of silt or clay bottom, where 94% of the surface fauna in the samples were noted on the photographs. Next highest was 43% for boulders in sandy silt. Both kinds of bottom are characterized by numerous annelid worm tubes projecting above the soft sediment; these account for the high percentage of visible surface fauna. The photo-

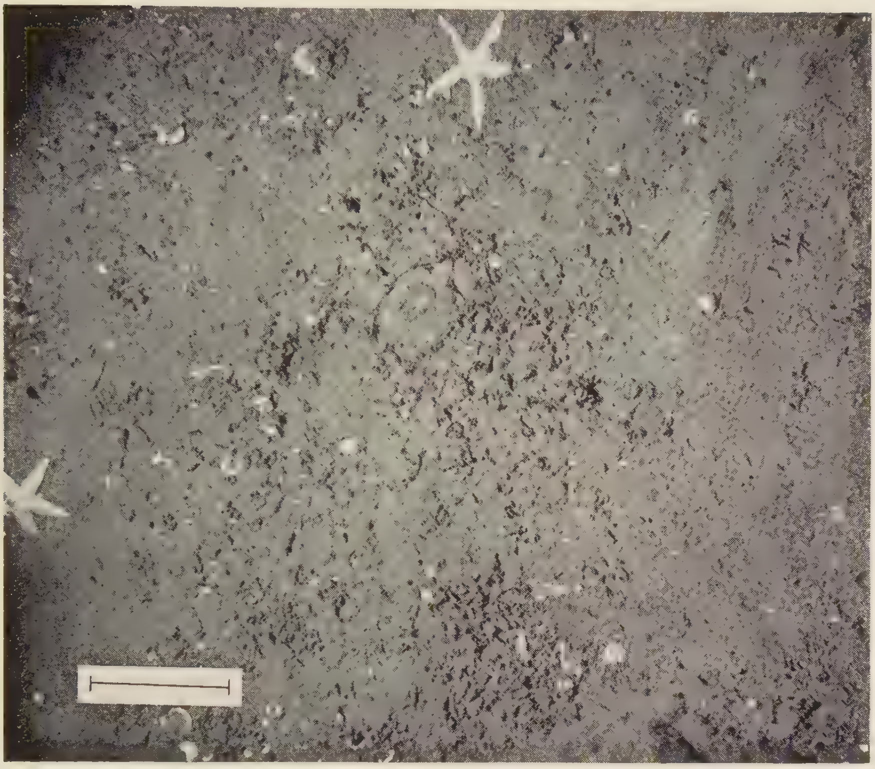


FIG. 15. Photograph at Station 1322 south of Long Island, New York (39°20.1′ N lat, 72°45.8′ W long, 84 m). Bottom sediment is sandy silt. The photograph shows two starfish, *Astropecten,* many partially covered fragments of the pelecypod *Venericardia borealis,* and a matlike carpet of very small annelid worm tubes (probably Sabellidae). Scale bar is 10 cm long.

graphs reveal 0–47% of total fauna (Table 5), with an average of only 16% for the eight kinds of substrate.

It might be argued that the photographs fail to reveal certain species within the general groups defined as surface fauna. This was investigated by counting in the samples the number of specimens belonging to species that were recognized in the photographs. The number of such specimens constitutes 0–49% and averages 17% of the total number of specimens in the defined surface fauna and is an even lower percentage of the total fauna (Table 5). The number of specimens of these species in the samples ranges from 0 to 123% of the number observed on corresponding photographs, expressed as averages for the eight types of substrate. Thus, even when the animals are selected as those most likely to be seen on the photographs, the correlation between photograph and sample is not very good. Of course, errors may occur through inadequacy of the sampling device or by slight lateral movement of the grab between the times of photographing and of closing upon the bottom materials. Such uncertainties remain to be investigated. Nevertheless, it seems obvious that photographic or direct visual examination can provide little information about the total number of organisms living on or in the bottom and, at best, only a weak estimation of their weight. The main value of photographs to biologists must be that of disclosing associations of various organisms and something of their habits, as is shown in Fig. 5. Quantitative estimates of numbers and biomasses must still rely primarily upon samples of the bottom. Of course,

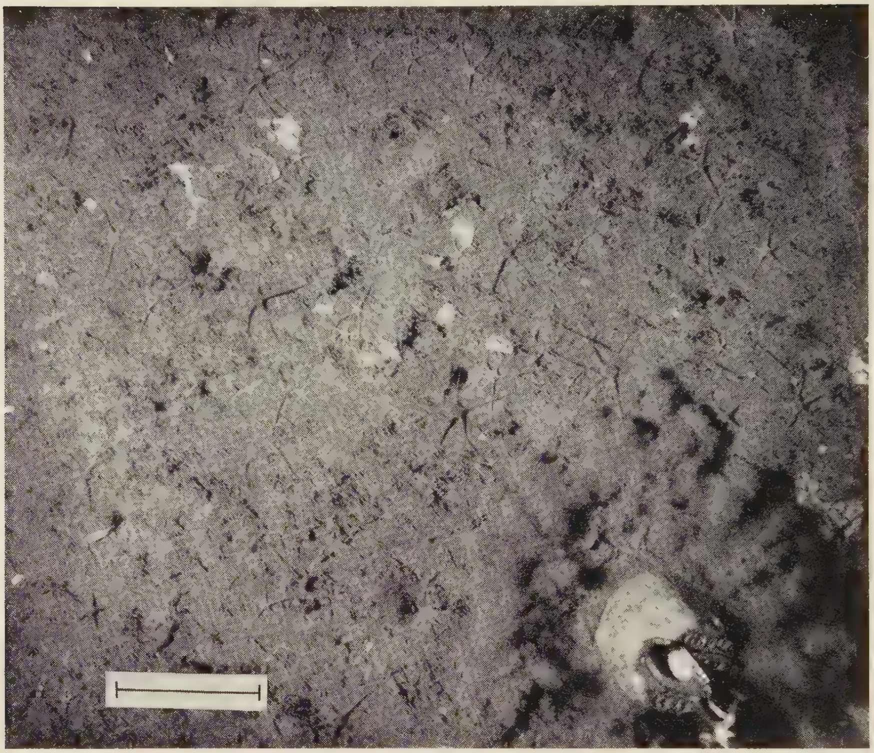


FIG. 16. Photograph at Station 1173 near entrance of Bay of Fundy (44°28.8′ N lat, 67°15.2′ W long, 116 m). Sediment is brown silty clay. Most obvious in the photograph are about 40 specimens of the brittle star, *Ophiura*, and a scattering of very small annelid worm tubes (Sabellidae). About 200 shells or shell fragments of ten species of mollusks were found in this sample, although only a few are visible in the photograph. Scale bar is 10 cm long.

TABLE 5. *Relationships of fauna observed in photographs to fauna in samples*

| Bottom type | No. surface fauna in sample | No. surface fauna in photo | % surface fauna in photo | % total fauna in photo | Species in photograph found in samples* | | | |
|---|---|---|---|---|---|---|---|---|
| | | | | | No. specimens | Ratio to no. in photo | Ratio to surface fauna | Ratio to total fauna |
| Boulders in sandy silt | 361 | 154 | 43 | 22 | 178 | 1.15 | 0.49 | 0.25 |
| Gravel or boulders and sand | 880 | 94 | 11 | 6 | 116 | 1.23 | 0.13 | 0.08 |
| Shelly sand | 870 | 1 | ~0 | ~0 | 0 | 0.00 | 0.00 | 0.00 |
| Shell hash | 68 | 0 | 0 | 0 | 0 | 0.00 | 0.00 | 0.00 |
| Sand and gravel | 282 | 61 | 22 | 17 | 71 | 1.17 | 0.25 | 0.19 |
| Sand | 381 | 101 | 27 | 24 | 47 | 0.47 | 0.12 | 0.11 |
| Sandy silt | 623 | 89 | 14 | 10 | 68 | 0.76 | 0.11 | 0.08 |
| Silt clay | 172 | 162 | 94 | 47 | 43 | 0.26 | 0.25 | 0.13 |
| Overall average | 455 | 83 | 26 | 16 | 65 | 0.63 | 0.17 | 0.11 |

* *See* text.

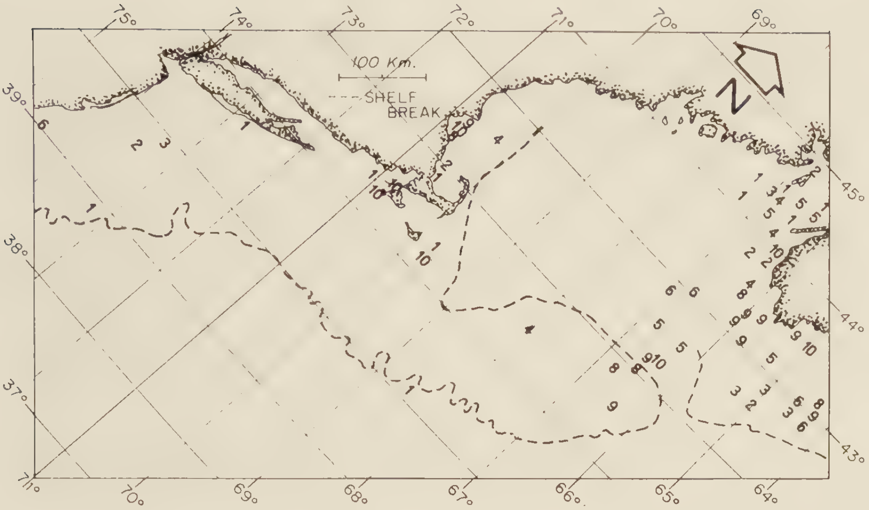


Fig. 17. Chart with numbers indicating the bottom area (in tenths) of each photograph composed of boulders or gravel (coarser than 4 mm diameter). *Compare with* Fig. 4.

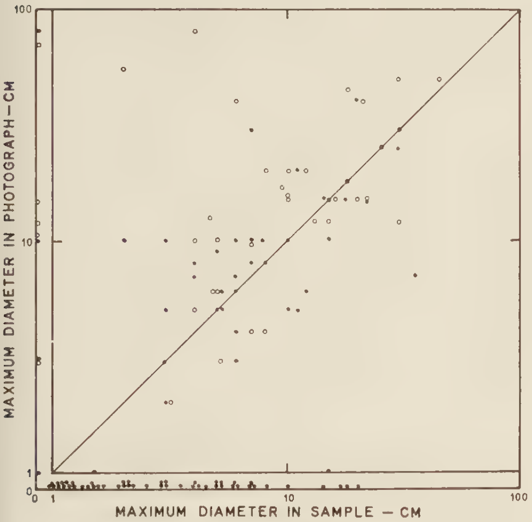


Fig. 18. Comparison of maximum diameter of pebbles, cobbles, or boulders measured on each photograph with the maximum found in corresponding samples. Solid dots represent bottoms that according to the photographs consist chiefly of sand, silt, or clay but contain some boulders, cobbles, or pebbles. Open circles represent bottoms that consist mainly of boulders or gravel with little or no fine-grained sediment. Note that the correlation between photograph and sample is better for the latter than for the former kind of bottom.

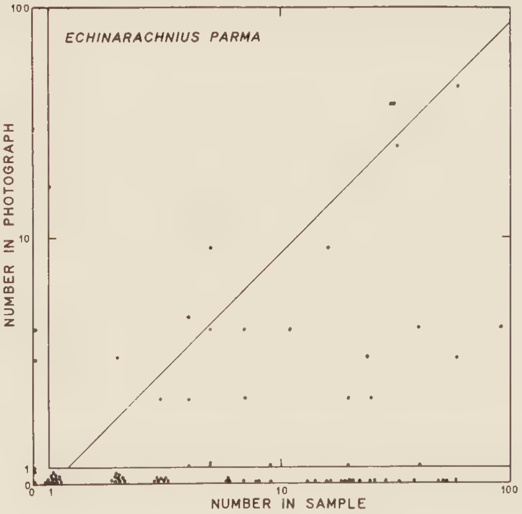
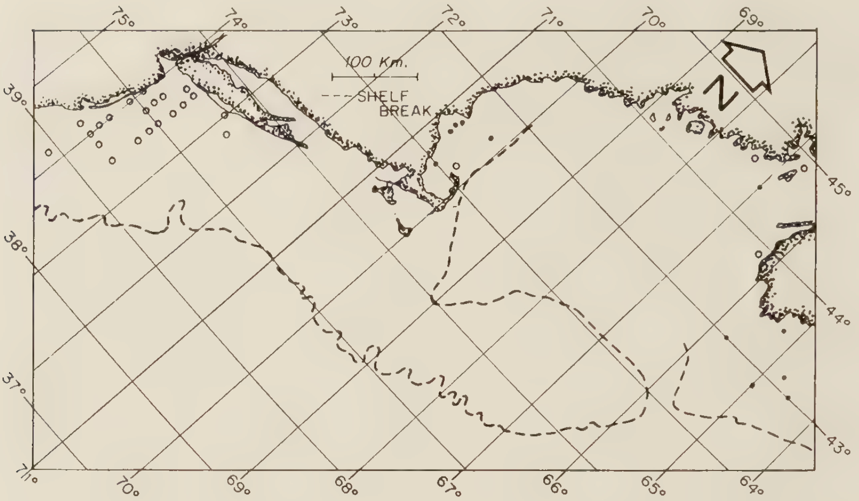


Fig. 19. Comparison of the number of sand dollars, *Echinarachnius parma*, observed in each photograph (*see* Fig. 14) with the number found in the corresponding samples. The diagonal line marks the positions of points if exact correspondence occurred, because it allows for the slightly different areas of photographs and samples (*see* Fig. 2). The usually greater number in the samples indicates that many are buried and not detectable in the photographs.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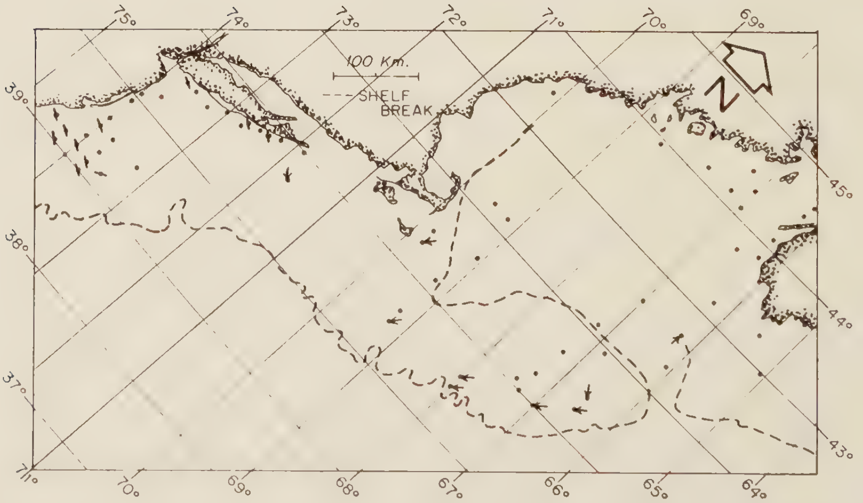
71°
70°
69°
68°
67°
66°
65°
64°

FIG. 20. Positions of stations having boulders or gravel covered by a film of silt (solid dots) and of stations having turbid water, as judged from the photographs (circles).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70°
69°
68°
67°
66°
65°
64°

FIG. 21. Positions of stations where photographs reveal wave or current markings. The lines indicate azimuth of water movement where a compass needle was in the field of view (*see* Fig. 12), and the arrowhead shows direction toward which the current moved where it could be determined. Current marks and asymmetrical ripple marks are present only east of the east end of Long Island, and symmetrical ripple marks occur only west of that point.

when the bottom is too rocky or bouldery for proper sampling, only a photograph can reveal the kinds of surface fauna in that area in a reasonably accurate way.

## REFERENCES

Boutan, L. 1900. La photographie sous-marine et les progrés de la photographie. Schleicher Frères, Paris. 332 p.

Carter, H. 1958. The histories of Herodotus of Halicarnassus. Heritage, New York. 615 p.

Cousteau, J. Y., and J. Dugan. 1963. The living sea. Harper and Row, New York. 325 p.

Edgerton, H. E., and L. D. Hoadley. 1955. Cameras and lights for underwater use. J. Soc. Motion Picture Television Engrs., **64**: 345–350.

Emery, K. O. 1952. Submarine photography with the benthograph. Sci. Monthly, **75**: 3–11.

———. 1960. The sea off southern California: a modern habitat of petroleum. Wiley, New York. 366 p.

Ewing, M., A. Vine, and J. L. Worzel. 1946. Photography of the ocean bottom. J. Opt. Soc. Am., **36**: 307–321.

———, G. P. Woollard, A. C. Vine, and J. L. Worzel. 1946. Recent results in submarine geophysics. Bull. Geol. Soc. Am., **57**: 909–934.

Hahn, J. 1950. Some aspects of deep sea underwater photography. J. Phot. Soc. Am. Sec. B, **16**(6): 27–29.

Haight, F. J. 1942. Coastal currents along the Atlantic coast of the United States. U.S. Coast Geodetic Surv. Spec. Publ. No. 230, 73 p.

Hartman, O. 1955. Quantitative survey of the benthos of San Pedro Basin, southern California, Part 1. Preliminary results. Allan Hancock Pacific Expeditions, **19**: 1–185.

Laughton, A. S. 1963. Microtopography, p. 437–472, v. 3. *In* M. N. Hill, E. D. Goldberg, C. O'D. Iselin, and W. H. Munk [eds.], The sea: ideas and observations on progress in the study of the seas. Interscience, New York.

Menzies, R. J., L. Smith, and K. O. Emery. 1963. A combined underwater camera and bottom grab: a new tool for investigation of deep-sea benthos. Intern. Rev. ges. Hydrobiol., **48**: 529–545.

Murray, J., and J. Hjort. 1912. The depths of the ocean: a general account of the modern science of oceanography based largely on the scientific researches of the Norwegian steamer Michael Sars in the North Atlantic. Macmillan, London. 821 p.

Owen, D. M. 1957. Deep sea photography at Woods Hole, p. 57–68. *In* H. Schenck, Jr., and H. Kendall [eds.], Underwater photograraphy, 2nd ed. Cornell Maritime Press, Cambridge, Md.

Seilacher, A. 1954. Die geologische Bedeutung fossiler Lebensspuren. Z. Deut. Geol. Ges., **105**: 214–227.

Shepard, F. P. 1939. Continental shelf sediments, p. 217–229. *In* P. D. Trask [ed.], Recent marine sediments. Am. Assoc. Petrol. Geologists, Tulsa, Okla.

———, and G. V. Cohee. 1936. Continental shelf sediments off the Mid-Atlantic states. Bull. Geol. Soc. Am., **47**: 441–458.

———, and K. O. Emery. 1946. Submarine photography off the California coast. J. Geol., **54**: 306–321.

Shipek, C. J. 1960. Photographic study of some deep-sea floor environments in the eastern Pacific. Bull. Geol. Soc. Am., **71**: 1067–1074.

Shrock, R. R. 1948. Sequence in layered rocks: a study of features and structures useful for determining top and bottom or order of succession in bedded and tabular rock bodies. McGraw, New York. 507 p.

Stewart, H. B., Jr., and G. F. Jordan. 1964. Underwater sand ridges on Georges Shoal, p. 102–114. *In* R. L. Miller [ed.], Papers in marine geology, Shepard Commemorative Volume. Macmillan, New York.

Wigley, R. L. 1961*a*. Bottom sediments of Georges Bank. J. Sediment. Petrol., **31**: 165–188.

———. 1961*b*. Benthic fauna of Georges Bank. Trans. N. Am. Wildlife and Nat. Resources Conf., 26th. Washington, D. C., 1961. Wildlife Management Inst.: 310–317.

Vinogradova, N. G. 1962. Some problems of the study of deep-sea bottom fauna. J. Oceanog. Soc. Japan, 20th Anniv. Vol.: 724–741.

Zenkevitch, L. A., N. G. Barsanova, and G. M. Belyaev. 1960. Quantitative distribution of bottom fauna in the abyssal area of the World Ocean [in Russian]. Dokl. Akad. Nauk SSSR, **130**: 183–186.

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# A SUBMERGED PEAT DEPOSIT OFF THE ATLANTIC COAST OF THE UNITED STATES

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# A SUBMERGED PEAT DEPOSIT OFF THE ATLANTIC COAST OF THE UNITED STATES[1]

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## ABSTRACT

A sample of salt-marsh peat from a depth of 59 m at the northwestern margin of Georges Bank has a radiocarbon age of 11,000 ± 350 years. No greater depth or age of salt-marsh peat lying exposed on the ocean floor elsewhere in the world are known to the authors. The age corresponds well with the date of ice retreat from the Gulf of Maine and with the ages of oyster and other shells that mark the advance of the ocean across the bank and the adjacent continental shelf.

## FIELD AND LABORATORY DATA

Commercial fishing boats that trawl for bottom fish and molluscs on the continental shelf frequently recover curious and unexpected objects in their nets, some of which are of considerable interest to geologists (Uchupi 1964). Recently (27 May 1964) Captain Norman Lepire of the New Bedford scallop trawler *Ruth Lea* reported the finding of an area of peat on Georges Bank (Fig. 1). A 1.5 kg sample from approximately 200 liters of peat, collected during a score or more tows of the scallop dredge, was given to the authors at the suggestion of John V. Mahoney and Robert Livingstone, Jr. Captain Lepire stated that the peat occurred in several small patches in an area about 1 km$^2$ at 41°09.3′ N lat and 68°43.2′ W long (position based on Loran-A fix) in a depth of 59 m. Patchiness of the peat was inferred from action of the dredge, which seemed to stick when dragged through the peat, substantially impeding the vessel's forward progress. Although the reported area of peat is reasonably large, it could not be relocated by three dredgings of *RV Gosnold* (Woods Hole Oceanographic Institution) and by four trawlings of *RV Albatross IV* (Bureau of Commercial Fisheries).

Much of the sample of peat contains borings of pelecypods (Fig. 2), showing that it lay exposed on the sea floor. Within some of the borings are specimens of *Zirfaea crispata* L. that were alive at the time of collection. This species is known to live at depths ranging from low-water mark to 130 m. The peat itself is a brown fibrous mass containing numerous twigs of woody land plants. Dr. Elso S. Barghoorn (Department of Biology, Harvard University) kindly examined two specimens and found that one contained many rhizomes of *Spartina* (a salt-marsh grass restricted to the range between mid- and high tide). The presence of *Spartina* in the peat identifies a past sea level more exactly than does the presence of estuarine mollusc shells. Also present were twigs and pollen largely from spruce (*Picea*) with some from pine (*Pinus*), and fir (*Abies*), and spores from peat moss (*Sphagnum*). The other specimen was freshwater peat containing many twigs, seeds, bud scales, and rootlets, some of which are cedar (*Cupressaceae*). Freshwater diatoms of the species *Pinnularia nobilis* Ehrenberg and *P. lata* (Brabisson) Wm. Smith were found in the peat by David Wall and R. R. Guillard of the

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[1] Contribution No. 1605 from the Woods Hole Oceanographic Institution, Woods Hole, Massachusetts.

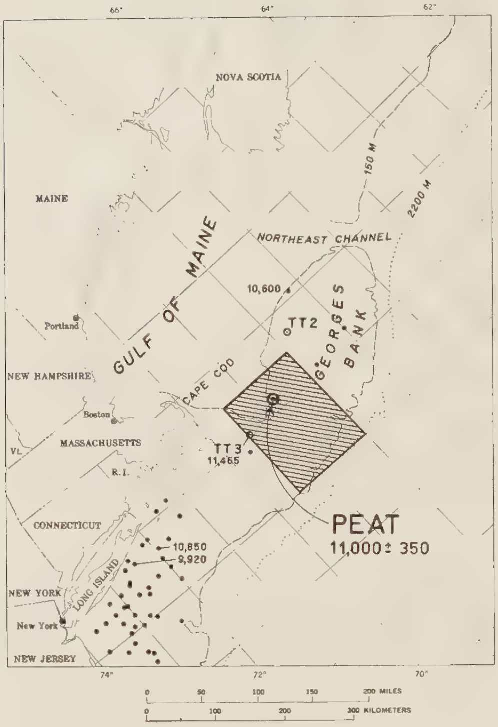

FIG. 1. General location of peat on Georges Bank. Cross-hatched rectangle denotes the area shown in detail in Fig. 3. Other localities of pertinent radiocarbon dates are indicated. Solid dots indicate the positions of samples containing oyster shells. TT denotes Texas Tower. The 150-m and 2,200-m contours denote the approximate position of the shelf-break and the base of the continental slope, respectively.

Woods Hole Oceanographic Institution (personal communication).

Radiocarbon dates based upon woody debris are generally considered to be more reliable than dates based upon carbon of shells. Accordingly, a portion of the peat was submitted to the U.S. Geological Survey for radiocarbon measurement. The larger twigs were removed, washed free of detrital sediment, and treated with dilute hydrochloric acid to remove any carbonate-carbon that might be present. The resulting age was found to be 11,000 ± 350 years B.P. (U.S.G.S. laboratory number W 1491). This age is greater than that reported for any other salt-marsh peat from the sea floor and is in accordance with the greater water depth. Freshwater peats containing spruce cones, pine, and arctic willow have been described by Kaye (1962) from Block Island (off Rhode Island), Martha's Vineyard (off Massachusetts), and Boston. Their radiocarbon ages are 11,000 to 12,000 years B.P.

Freshwater and marine peats have long been known from the North Sea and the Baltic Sea (Andrée 1920; Pratje 1933; Lüders 1939). The peat from Georges Bank appears to be similar in composition and origin.

## SIGNIFICANCE

The sample of peat is from the northwestern margin of Georges Bank at a point separated from the mainland by Great South Channel (Fig. 3). The floor of the channel is 20 to 25 m deeper than the sample site. The presence of this channel, the large size of the original peat sample, the borings on only one side of the larger pieces, and the great age of the peat preclude the possibility that the deposit consists only of masses of peat carried from shore. Great South Channel probably was occupied by a tongue of the ice lobe that filled the Gulf of Maine during the late part of the Pleistocene epoch. Thus, the peat must have been deposited after the ice retreated.

As shown by Zeigler et al. (1964), the Cape Cod sea cliffs of stratified sandy glacial drift contain reworked marine shells. Radiocarbon ages of two sets of the shells are 26,900 ± 700 years and 20,700 ± 2,000 years (middle and top of cliff respectively). These shells were picked up by the ice as it moved across the floor of the Gulf of Maine and Cape Cod Bay; thus, they are older than the glacial deposit that now contains them. Several minor advances of ice are recorded in the region by drift sheets separated by bedded silts and clays. The latest ice sheet appears to have retreated from the Connecticut coast more than 13,500 years ago, as shown by radiocarbon dates of peat samples from the bottoms of bogs (Bloom 1963). A tundra peat on Martha's Vineyard (Ogden 1963; Rubin and Alexander 1960) indicates that the ice was gone from there about

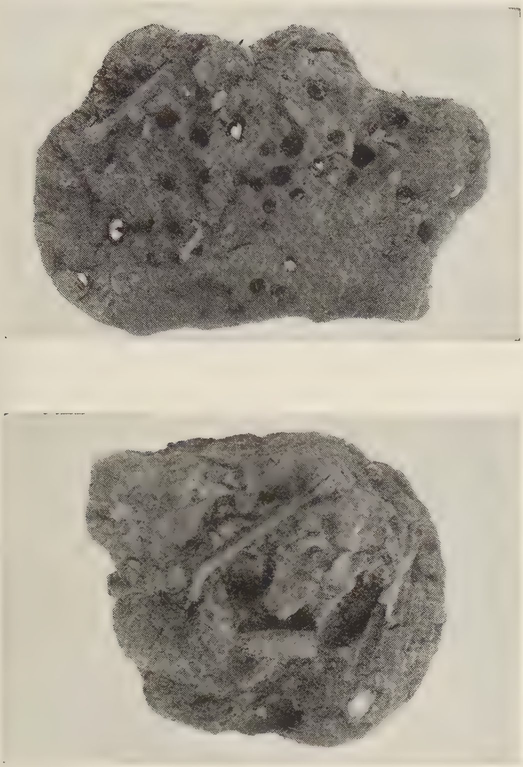

FIG. 2. Photograph of top and bottom of the two 15-cm wide slabs of peat from Georges Bank. Note the pelecypod borings in the surface exposed to water and the woody twigs within the peat.

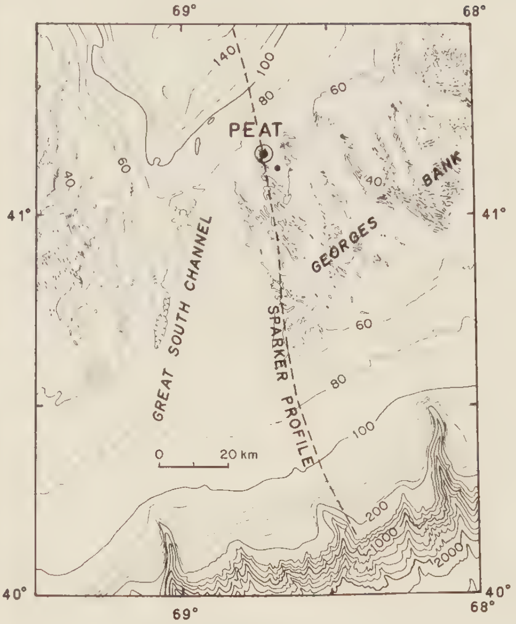

FIG. 3. Position of the peat deposit. This contour map is an enlargement of the area indicated by cross-hatched rectangle on Fig. 1. The irregular 40-m and 60-m contours on Georges Bank denote sand waves that appear to be actively moving westward. The dot about 7 km southeast of the peat locality marks the position of a sample containing a dated oyster shell. The dashed line indicates the track of a sparker profile, part of which is reproduced in Fig. 4.

12,700 years ago. The ice left the Boston area about 12,300 years ago, according to radiocarbon dating of various glacial and glaciofluvial deposits reported by Kaye and Barghoorn (1964). A retreat of ice from the Portland area occurred about the same time or a little earlier, but it was followed by a re-advance that lasted until between 10,200 and 11,200 years ago, according to Bloom (1963). The peat from Georges Bank indicates that this area was free of ice about 11,000 years ago and that sea level had risen to a point on the bank now 59 m below sea level. The type of pollen shows that the climate still was cold.

Supporting evidence for nearshore marine deposits atop the margin of Georges Bank is provided by empty shells of the shallow-water edible oyster *Crassostrea virginica* (Gmelin) lying exposed or covered by only a few centimeters of sandy sediment at four localities on the bank. The shells at one of the sites (53 m depth near the northeastern edge of Georges Bank, Fig. 1) were reported by Medcof, Clarke, and Erskine (1965) as dating from 10,600 ± 130 years B.P. Oyster shells also were reported by Merrill, Emery, and Rubin (1965) at 70 localities on the continental shelf farther west. Ages for these shells range from 8,130 to 10,850 years, with present water depths from 33 to 55 m for dated shells; occasional undated specimens occur as deep as 82 m. This wide depth range agrees with the belief that the shells were deposited in a series of lagoons that bordered the coast as sea level rose and the ocean transgressed the continental shelf.

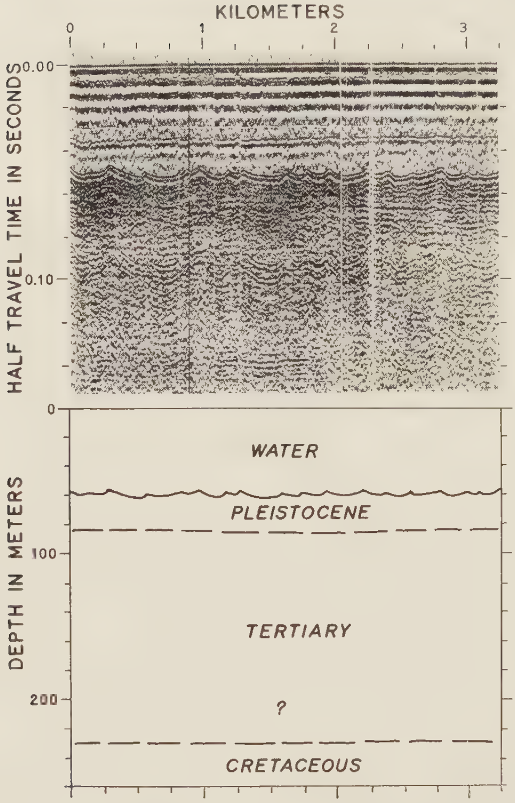

FIG. 4. Continuous seismic (sparker) profile from south (left) to north (right) through the peat locality (middle) along part of the track line shown by Fig. 3. The stratigraphy (bottom) is inferred from the record and from bottom samples collected elsewhere on Georges Bank. Seismic speeds are assumed as 1,500 m/sec for the water and 2,000 m/sec for the sediments.

The peat site on Georges Bank is at the north end of one of a series of large sand waves (Fig. 3) that were described by Stewart and Jordan (1964). The shallow waves were reported to be actively moving toward the west at a rate of about 10 m/year. One of the sand waves was penetrated to a depth of about 55 m below sea level by several foundation test drillings for Texas Tower No. 2. Between the sea floor (at about 17 m depth) and a depth of 40 m below sea level, the drill passed through only sand and gravel, but between 40 and 55 m it encountered silt (W. D. Athearn, personal communication). Three test borings for Texas Tower No. 3, penetrated a similar sand wave west of Great South Channel and recovered samples from a similar layer of silt between depths of 46 and 62 m below sea level; this depth is about the same as that of the base of the sand wave. Silt from one of the drillings was examined by Groot and Groot (1964) and Livingstone (1964) who found Quaternary, Cenozoic, and Cretaceous spores and pollen. Also present in the silt was a shell of *Crepidula fornicata* (L.) having a radiocarbon age of 11,465 ± 400 years (Zeigler et al. 1964).

Continuous seismic (sparker) profiles across the bank have been made as part of a general survey of the continental shelf by Woods Hole Oceanographic Institution and the U.S. Geological Survey (Emery and Schlee 1963). A profile at the peat locality shows sand waves at the sea-floor surface underlain by an unconformity not more than 25 m deeper (Fig. 4). Below the unconformity are strata having a gentle dip and probably of the Pliocene to Cretaceous age, the same as represented by many fragments recovered from gravels atop the bank mapped by Wigley (1961). The sparker evidence suggests that the peat was deposited on top of bedrock or on thin silts atop the bedrock and that it is being covered by moving sand waves.

Since the date of the peat deposition, sea level has risen more or less steadily. Its rise is well recorded during the past 4,000 or 5,000 years by radiocarbon dates of salt-marsh and other deposits near Portland (Bloom 1963), Boston (Kaye and Barghoorn 1964), at the inside of the hook of Cape Cod (Redfield and Rubin 1962), and along the Connecticut coast (Bloom 1964; Bloom and Stuiver 1963).

Reconstruction of the recent geological history of Georges Bank suggests that it formed the southern border of an ice lobe that filled the Gulf of Maine. Tongues of ice probably protruded oceanward through broad channels at each end of the bank (Figs. 3, 5). Outwash sands and gravels were deposited on top of Cenozoic strata that formed the preglacial surface of the bank. About 12,300 years ago or a little

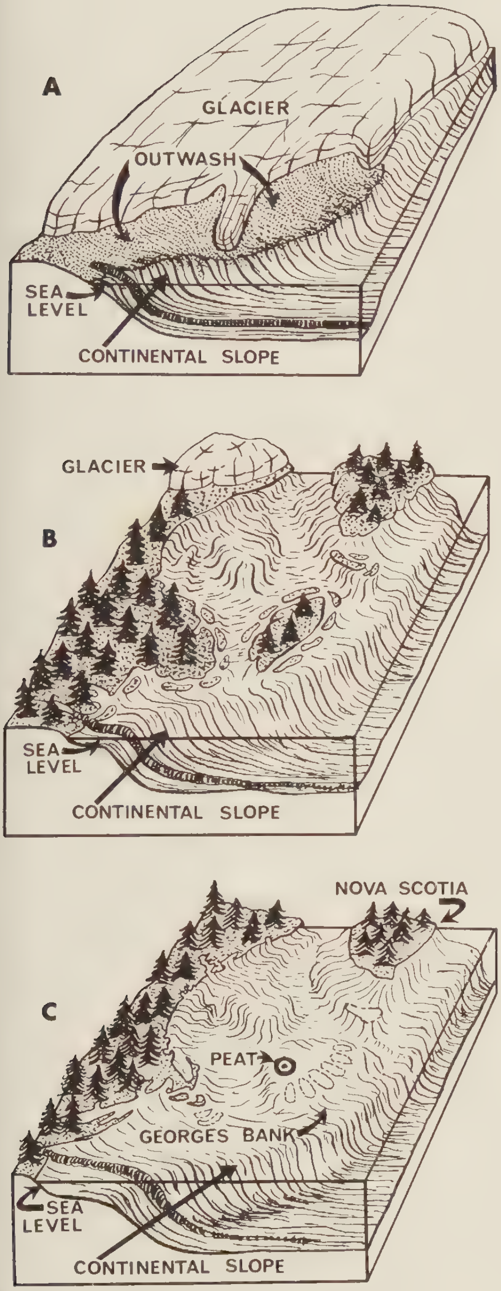

Fig. 5. Sketches showing Georges Bank and its surroundings (A) about 20,000 years ago when glacial ice abutted the bank, (B) about 11,000 years ago when the peat was deposited, and (C) at present. Drawn by Nicholas R. Serbu, U.S. Geological Survey.

earlier, the ice retreated. By 11,000 years ago, sea level had risen above the rim of the bank, and offshore bars created estuaries and lagoonal areas of quiet water where salt-marsh peat accumulated (Fig. 5). These shallow-water areas also served as sites for oysters of the kind now living in estuaries and lagoons of the mainland. The top of the bank projected 40 to 50 m above the ocean and was at least partly covered by boreal forests. Continued rise of sea level drowned the salt marshes and their lagoons. Subsequently, wave and tidal energy reworked the sandy glacial outwash into the shifting sand waves of the present. Future exploration may uncover additional remnants of the ancient salt marsh around the perimeter of the bank and beneath the sand waves, but the movements of the sand waves have been so great that remnants of marshes within the sand are unlikely to have been preserved.

## REFERENCES

Andrée, K. 1920. Geologie des Meeresbodens, II: Borntraeger, p. 1–689. Leipzig.

Bloom, A. L. 1963. Late Pleistocene fluctuations of sealevel and postglacial rebound in coastal Maine. Am. J. Sci., **261**: 862–879.

———. 1964. Peat accumulation and compaction in a Connecticut coastal marsh. J. Sediment. Petrol., **34**: 599–603.

———, and M. Stuiver. 1963. Submergence of the Connecticut coast. Science, **139**: 332–334.

Emery, K. O., and J. S. Schlee. 1963. The Atlantic continental shelf and slope, a program for study, p. 1–11. U.S. Geol. Surv. Circ. 481.

Groot, C. R., and J. J. Groot. 1964. The pollen flora of Quaternary sediments beneath Nantucket Shoals. Am. J. Sci., **262**: 488–493.

Kaye, C. A. 1962. Early postglacial beavers in southwestern New England. Science, **138**: 906–907.

———, and E. S. Barghoorn. 1964. Late Quaternary sea-level change and crustal rise at Boston, Massachusetts, with note on the autocompaction of peat. Bull. Geol. Soc. Am., **75**: 63–80.

Livingstone, D. A. 1964. The pollen flora of submarine sediments from Nantucket Shoals. Am. J. Sci., **262**: 479–487.

Lüders, K. 1939. Sediments of the North Sea, p. 322–342. *In* P. D. Trask [ed.], Recent marine sediments. Am. Assoc. Petrol. Geol., Tulsa, Oklahoma.

Medcof, J. C., A. H. Clarke, Jr., and G. S. Erskine. 1965. Ancient Canadian east-coast nental shelf. Science, **147:** 398–400.

Ogden, J. G., III. 1963. The Squibnocket cliff peat: radiocarbon dates and pollen stratigraphy. Am. J. Sci., **261:** 344–353.

Pratje, O. 1933. Der glaziale Untergrund der heutigen Sediments in Bornholmer Becken. Deut. Geol. Ges. Z., **85:** 730–739.

Redfield, A. C., and M. Rubin. 1962. The age of salt marsh peat and its relation to recent changes in sea level at Barnstable, Massachusetts. Proc. Natl. Acad. Sci. U.S., **48:** 1728–1735.

Rubin, M., and C. Alexander. 1960. U.S. Geological Survey radiocarbon dates. V. Am. J. Sci., Radiocarbon Suppl., **2:** 129–185.

Stewart, H. B., Jr., and G. F. Jordan. 1964. Underwater sand ridges on Georges Shoal, p. 102–114. *In* R. L. Miller [ed.], Papers in marine geology. Shepard commem. volume. Macmillan, New York.

Uchupi, E. 1964. Unusual hauls from Georges Bank. Oceanus, **10:** 20–22.

Wigley, R. L. 1961. Bottom sediments of Georges Bank. J. Sediment. Petrol., **31:** 165–188.

Zeigler, J. M., S. D. Tuttle, H. J. Tasha, and G. S. Giese. 1964. Pleistocene geology of Outer Cape Cod. Bull. Geol. Soc. Am., **75:** 705–714.

# COMPOSITION OF BASALTS DREDGED FROM SEAMOUNTS OFF THE WEST COAST OF CENTRAL AMERICA

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*Abstract.*—Two alkali basalts and a third, intermediate in composition between tholeiitic and alkali basalts, have been dredged from the surficial parts of three submarine volcanoes on the Cocos Ridge, eastern Pacific Ocean. The two alkali basalts contain (in weight percent, calculated water free): $SiO_2$, 44.6; $Na_2O+K_2O$, 4.8 to 5.8; and appreciable amounts of the trace elements Ba, Sr, and Zr. The intermediate type contains: $SiO_2$, 48.8; $Na_2O+K_2O$, 3.7; and smaller amounts of most trace elements except Cu. Alkali basalts, similar to those from the Cocos Ridge, form the apical parts of most large volcanoes throughout the oceans.

Expedition Criss-Cross of the Scripps Institution of Oceanography, University of California, successfully dredged samples of volcanic rock from the near-surface parts of three seamounts west and southwest of Cocos Island, and north of the Galapagos Islands, in the Pacific Ocean. This note discusses the chemistry and petrography of these submarine igneous rocks.

The forms of the submarine volcanoes from which the samples were dredged are shown in figure 1. These features lie along the northwest flank of Cocos Ridge, which extends from about lat 2° N. and long 94° W. to the southwest coast of Costa Rica and Panama (fig. 1). The Cocos Ridge, in turn, is a spur of the huge East Pacific Rise (Menard, 1960).

All the rocks recovered in the dredge hauls are basalts. Locations of the samples and depths of dredge sites are given at the bottom of the accompanying table. Dredge hauls ranged in depth from 150 to 250 fathoms.

Sample 312 was recovered from the upper part of a submarine volcano about 180 miles north of the Galapagos Islands and 290 statute miles southwest of Cocos Island (fig. 1). It is a light-gray dense basalt. In thin section the rock has a diabasic to fluidal structure and contains (in volume percent): plagioclase, 58; augite,

*Chemical composition of basalts dredged from seamounts off the west coast of Central America*

| | Sample 312 | | Sample 314 | | Sample 316 | |
|---|---|---|---|---|---|---|
| | Original | Water free | Original | Water free | Original | Water free |
| **Oxides, in weight percent [1]** | | | | | | |
| $SiO_2$ | 48.34 | 48.83 | 44.90 | 45.57 | 42.95 | 44.61 |
| $TiO_2$ | 1.97 | 1.99 | 2.85 | 2.89 | 2.81 | 2.92 |
| $Al_2O_3$ | 16.36 | 16.53 | 22.80 | 23.13 | 19.10 | 19.84 |
| $Fe_2O_3$ | 2.59 | 2.62 | 1.91 | 1.94 | 4.03 | 4.18 |
| FeO | 7.38 | 7.46 | 4.69 | 4.76 | 5.60 | 5.81 |
| MnO | .17 | .17 | .12 | .12 | .16 | .16 |
| MgO | 6.23 | 6.29 | 5.09 | 5.16 | 6.65 | 6.90 |
| CaO | 11.97 | 12.09 | 9.16 | 9.30 | 9.37 | 9.73 |
| $Na_2O$ | 2.91 | 2.94 | 4.00 | 4.06 | 3.50 | 3.63 |
| $K_2O$ | .79 | .80 | 1.76 | 1.79 | 1.15 | 1.19 |
| $H_2O+$ | .27 | ------- | .54 | ------- | 1.84 | ------ |
| $H_2O-$ | .55 | ------- | .66 | ------- | 1.46 | ------ |
| $P_2O_5$ | .28 | .28 | 1.26 | 1.28 | .99 | 1.03 |
| Total | 99.81 | ------- | 99.74 | ------- | 99.61 | ------ |
| **Elements, in parts per million [2]** | | | | | | |
| Ba | 220 | ------- | 740 | ------- | 810 | ------ |
| Co | 33 | ------- | 22 | ------- | 27 | ------ |
| Cr | 46 | ------- | 120 | ------- | 180 | ------ |
| Cu | 62 | ------- | 34 | ------- | 48 | ------ |
| Ga | 22 | ------- | 19 | ------- | 20 | ------ |
| La | <80 | ------- | 120 | ------- | <80 | ------ |
| Nb | 31 | ------- | 82 | ------- | 70 | ------ |
| Ni | 45 | ------- | 63 | ------- | 60 | ------ |
| Sc | 38 | ------- | 30 | ------- | 33 | ------ |
| Sr | 320 | ------- | 740 | ------- | 440 | ------ |
| V | 290 | ------- | 250 | ------- | 320 | ------ |
| Y | 40 | ------- | 52 | ------- | 52 | ------ |
| Yb | 4 | ------- | 4 | ------- | 5 | ------ |
| Zr | 150 | ------- | 340 | ------- | 260 | ------ |

Ag <3, B <30, Be <2, Mo <5.

Sample 312. Paramount Bank; lat 3°20′ N., long 90°45′ W. Depth 165 fathoms.

Sample 314. Unnamed seamount; lat 4°58′ N., long 87°28′ W. Depth 250 fathoms.

Sample 316. West Cocos Seamount; lat 5°28′ N., long 88°33′ W. Depth 150 fathoms.

[1] Major element analyses by C. G. Engel.

[2] Quantitative spectrographic analyses (±15 percent) by R. G. Havens.

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[1] U.S. Bureau of Commercial Fisheries.

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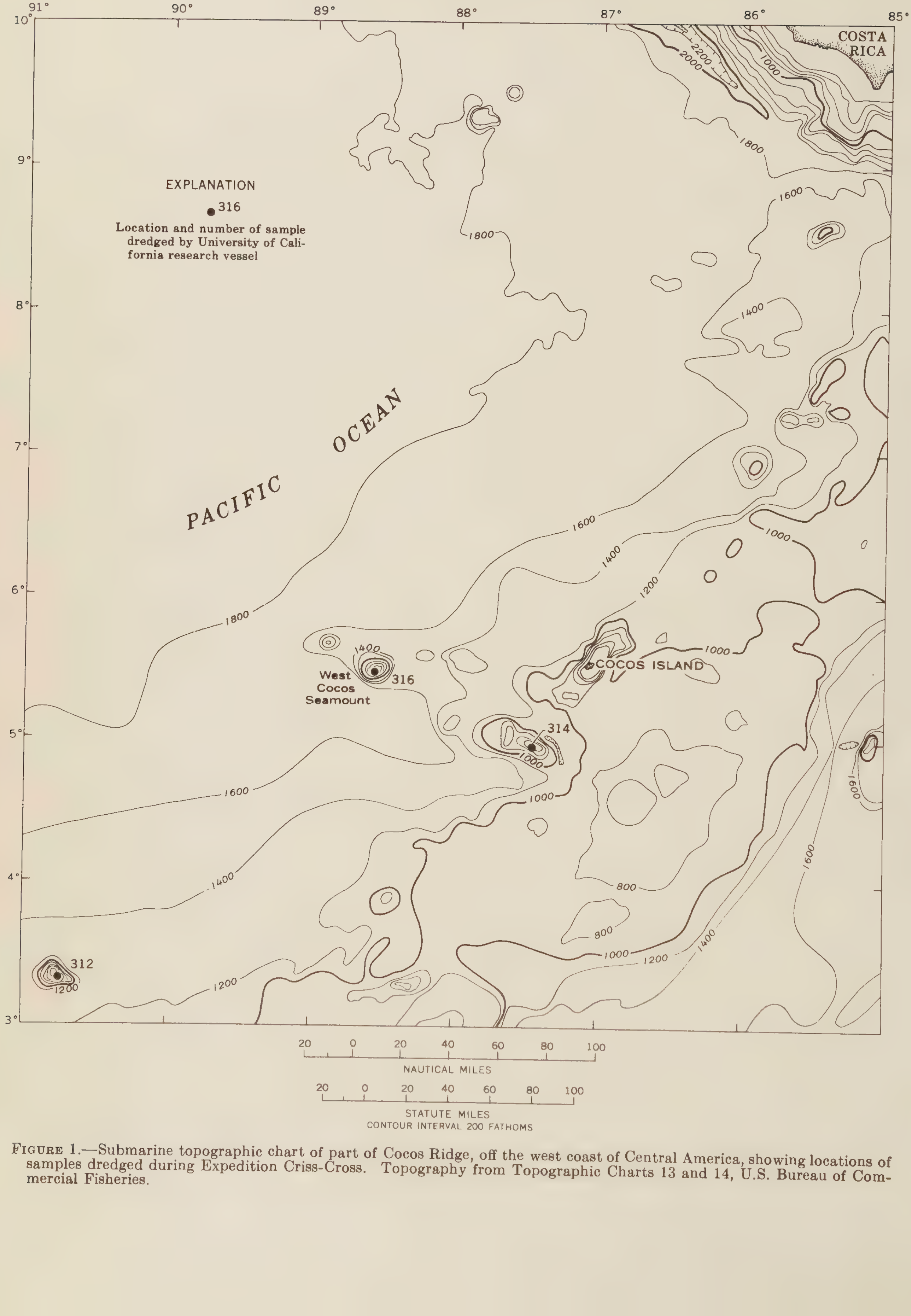
91°
90°
89°
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4°
3°
COSTA RICA
2200
2000
1000
1800
1600
1400
1200
1000
800
600
EXPLANATION
● 316
Location and number of sample dredged by University of California research vessel
PACIFIC OCEAN
West Cocos Seamount
316
314
312
COCOS ISLAND
NAUTICAL MILES
STATUTE MILES
20 0 20 40 60 80 100
CONTOUR INTERVAL 200 FATHOMS

FIGURE 1.—Submarine topographic chart of part of Cocos Ridge, off the west coast of Central America, showing locations of samples dredged during Expedition Criss-Cross. Topography from Topographic Charts 13 and 14, U.S. Bureau of Commercial Fisheries.

38; opaque minerals, 3; and alteration products, principally palagonite, 1. The chemical composition of basalt 312 (see table) is intermediate between the composition of low-potassium oceanic tholeiites and typical alkali basalts of submarine volcanoes and islands. The average $K_2O$ content of low-potassium tholeiites is 0.17 weight percent, whereas typical alkali basalts capping submarine volcanoes and islands contain about 1.5 weight percent of $K_2O$ (Engel and Engel, 1963; 1964a; 1964b). Tholeiitic basalts similar in composition to basalt 312 also occur on the Galapagos Islands (Banfield and others, 1956). Tholeiites are, however, commonly subordinate to alkali basalts on the islands and higher submarine volcanoes of the East Pacific Rise.

Sample 314 is a gray vesicular porphyritic alkali basalt from the crest of an unnamed seamount (see table and fig. 1). It contains vesicles and tubules as much as 7 mm long. In thin section the rock consists of the following constituents (in volume percent): a fine-grained groundmass, principally a mat of plagioclase and opaque minerals, 45; labradorite phenocrysts, 18; olivine, clear and unaltered, 5; vesicles, 27; opaque minerals, 4; and calcite, lining walls of vesicles, about 1.

Sample 316 is a gray vesicular porphyritic alkali basalt from the upper part of the West Cocos Seamount. It contains almond-shaped vesicles that are as much as 20 mm long. The phenocrysts are labradorite and pale pink augite. The rock contains (in volume percent): plagioclase, 60; augite, 20; opaque minerals, 8, and vesicles, 6. It is the most altered of the basalts studied and contains approximately 6 volume percent palagonite and other alteration products. Both of the alkali basalts 314 and 316 contain numerous tiny crystals of apatite.

The concentrations of trace elements in the basalts (see table) reflect their major element compositions. Distinct differences exist between the amounts of trace elements in basalt 312 and the amounts in the alkali basalts 314 and 316. The alkali basalts contain more Ba, Sr, Zr, Nb, Cr and Ni, than does basalt 312. The increases in amounts of Ba, Sr, and Zr, with an increase in sodium and potassium in the alkali basalts, are predictable on the basis of chemical coherence and have been observed in the Hawaiian lava series by Wager and Mitchell (1953). The enrichment of Cr and Ni in the alkali basalts, 314 and 316, could hardly be predicted and appears to be anomalous. There is less Cu in the alkali basalts than in basalt 312.

The composition and occurrence of the basalts 312, 314, and 316 are consistent with what is known regarding volcanic rocks throughout other parts of the East Pacific Rise (Chubb and Richardson, 1933; Bandy, 1937; Banfield and others, 1956; Engel and Engel, 1963, 1964b). Cappings of the higher volcanoes are composed largely of alkali basalts and other members of the alkali-rich series. The deeply submerged flanks of the East Pacific Rise appear to consist largely of low-potassium, tholeiitic basalts. Engel and Engel (1964a, 1964b) have suggested that this low-potassium basalt represents the primary magma erupted from the mantle. The alkali basalts and derivative alkali-rich members appear to be derived from the low-potassium basalts by magmatic differentiation.

## REFERENCES

Bandy, N. C., 1937, Geology and petrology of Easter Island; Geol. Soc. Am. Bull., v. 48, p. 1589–1610.

Banfield, A. F., Behre, C. H., Jr., and St. Clair, David, 1956, Geology of Isabela (Albemarle) Island, Archipielago de Colon (Galapagos): Geol. Soc. Am. Bull., v. 67, p. 215–234.

Chubb, L. J., and Richardson, Constance, 1933, Geology of Galapagos, Cocos, and Easter Islands: Bernice P. Bishop Museum Bull. 110, 67 p.

Engel, A. E. J., and Engel, C. G., 1964a, Composition of basalts from the Mid-Atlantic Ridge: Science, v. 144, no. 3624, p. 1330–1333.

——— 1964b, Igneous rocks of the East Pacific Rise: Science, v. 146, no. 3643, p. 477–485.

Engel, C. G., and Engel, A. E. J., 1963, Basalts dredged from the northeastern Pacific Ocean: Science, v. 140, no. 3573, p. 1321–1324.

Menard, H. W., 1960, The East Pacific Rise: Science, v. 132, no. 3441, p. 1737–1746.

Wager, L. R., and Mitchell, R. L., 1953, Trace elements in a suite of Hawaiian lavas: Geochim. et Cosmochim. Acta, v. 3, p. 217–223.

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40. *Some Effects of an Acute Dose of* $Co^{60}$ *Gamma Radiation on the Blood of the Pinfish,* Lagodon rhomboides. David W. Engel, Joseph W. Angelovic,* and Edna M. Davis,* Bureau of Commercial Fisheries, Radiobiological Laboratory, Beaufort, North Carolina.

Changes in the blood of the pinfish, *Lagodon rhomboides*, were observed following an acute whole-body radiation dose of 2,000 r which was administered at 435 r/min. Blood samples were obtained immediately following irradiation and on alternate days for 34 days. Modified clinical laboratory procedures were used to determine the numbers of erythrocytes, leucocytes, and thrombocytes, hemoglobin levels, hematocrit values, plasma protein levels, and mean blood cell volumes. Leucocyte and thrombocyte numbers started to decrease the day after irradiation, reached their lowest levels on the 3rd and 7th days, and then increased to the level of the controls by the 15th day. While only a slight change was observed in the numbers of erythrocytes, hemoglobin levels, and hematocrit values, morphological changes did occur in the erythrocytes. These changes consisted of alterations in mean cell volume and distortion of nuclei and cellular form. The numbers of reticulated erythrocytes began to increase on the 7th day and all appeared reticulated by the end of the experiment. The plasma protein level declined more rapidly in the irradiated fish than in the controls during the first 3 weeks of the experiment and then returned to the control level by the 23rd day. These results indicate that 2,000 r definitely has an effect on the hematopoietic system of pinfish.

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# Fat Content of the Flesh of Siscowets and Lake Trout from Lake Superior

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# Fat Content of the Flesh of Siscowets and Lake Trout from Lake Superior

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## ABSTRACT

Samples of flesh were excised from the middorsal region of 67 siscowets (*Salvelinus namaycush siscowet*) and 46 lake trout (*Salvelinus n. namaycush*) collected from Lake Superior. Chemical analysis of the samples revealed a range in fat content (dry weight) of 32.5 to 88.8 per cent in siscowets and 6.6 to 52.3 per cent in lake trout. Percentage fat increased progressively with increase in length of fish in both forms, but the average rate of increase was far greater for siscowets than for lake trout at lengths between 12 and 20 inches. Despite substantial individual variation, the percentage fat in the two forms was widely different and without overlap at all comparable lengths. The range in iodine number of the fat was 100 to 160 for siscowets and 103 to 161 for lake trout; average values were generally lower for siscowets than for lake trout among fish of comparable length. Percentage fat and relative weight were not correlated significantly in either subspecies. The fat content of flesh samples from a distinctive subpopulation of Lake Superior lake trout known as "humpers" was more closely similar to that of typical lean lake trout than to siscowets, but the rate of increase in fat with increasing length was greater than for lean lake trout. Flesh samples from hatchery-reared stocks of lake trout, hybrid lake trout × siscowets, and siscowets tended to support the view that the wide difference in fat content between siscowets and lake trout is genetically determined.

## INTRODUCTION

The identity of a number of subpopulations of lake trout, *Salvelinus namaycush*, in Lake Superior is revealed by differences in spawning localities and/or dates, and size at first maturity (Eschmeyer, 1957). Although fish of the different subpopulations are not easily recognizable by sight, commercial fishermen differentiate between, and market separately, two forms which usually are given subspecific rank—the "lean" lake trout, *Salvelinus n. namaycush*, and the siscowet or "fat" lake trout, *Salvelinus n. siscowet.* The lean lake trout of Lake Superior is similar to fish of many other populations of the species in waters throughout its range, but the siscowet has somewhat different appearance and characteristics, and is believed to be confined to the Upper Great Lakes—principally to Lake Superior.

Most siscowets are caught at depths of 50 to more than 100 fathoms, in contrast to lake trout, which usually are caught in shallower water. The bathymetric distribution of the two forms overlaps broadly, however; occasional siscowets are taken in shallow water, and lake trout and siscowets are sometimes taken in about equal numbers in gill nets at depths greater than 50 fathoms. Typical siscowets are deep-bodied fish with oily flesh, and are sold as "fats" or "half-breeds."[1] Even though the obesity of some siscowets is striking, half-breeds are sometimes difficult for the untrained observer to distinguish from lake trout. Most siscowets are smoked for the market because they are too oily to be prepared satisfactorily by other cooking methods. In recent years they usually have been sold at a lower price than lake trout, but apparently this price difference has not always existed. Goode (1884) reported that the siscowet ". . . fetches double the price per barrel . . ." as compared to lake trout.

The question of the taxonomic position of the siscowet has been a source of disagreement. It was described as a new species (*Salvelinus siscowet*) by Agassiz (1850). Goode (1884) quoted Robert Sweeny (then Chairman of the Minnesota Fish Commission), as saying that the siscowet ". . . is not possibly a 'Namaycush' and should never be considered the same fish . . . ." On the other hand, Jordan and Evermann (1911), although they retained the subspecific classification of the siscowet listed by Jordan and Gilbert (1883),

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[1] Illustrations of siscowets were published by Jordan and Evermann (1911), Eddy and Surber (1947), and Thurston (1962).

TABLE 1.—*Dates, localities, and depths of capture of siscowets and lake trout collected for determination of fat content, Lake Superior, 1953–61*

| Date | Locality | Station[1] | Depth (fathoms) | Number of fish | Total length (inches) |
|---|---|---|---|---|---|
| Siscowets | | | | | |
| 10 June 1953 | Marquette | — | — | 3 | 17.9–28.8 |
| 26 July–29 Sept. 1953 | Isle Royale | 2 | 19–31 | 3 | 17.3–24.7 |
| 3 Sept. 1953 | Keweenaw Bay | 6 | 34 | 1 | 21.8 |
| 30 Aug. 1954 | Marquette | 8 | 55–65 | 20 | 11.8–26.1 |
| 28 Sept. 1954 | Caribou Island | 13 | 50–80 | 40 | 15.7–32.8 |
| Lake trout | | | | | |
| 13 June 1953 | Laughing Fish Point | 10 | 22 | 4 | 15.2–16.7 |
| 14–19 June 1953 | Munising | 11 | 25–37 | 3 | 13.0–25.0 |
| 15 June 1953 | Grand Marais (Mich.) | 12 | 33–40 | 6 | 14.3–18.7 |
| 5–7 Nov. 1954 | Marquette | 9 | 10 | 3 | 30.0–38.0 |
| 7 Nov. 1954 | Laughing Fish Point | 10 | 10 | 3 | 32.0–37.3 |
| 23 Aug. 1955 | Laughing Fish Point | 10 | 27 | 16 | 9.4–12.2 |
| 4–5 Oct. 1956 | Marquette | 9 | 10 | 4 | 28.1–31.3 |
| 24 Oct. 1961 | West Portage Entry | 5 | 15 | 3 | 21.4–22.6 |
| 24–25 Oct. 1961 | Huron Islands | 7 | 21 | 4 | 19.3–20.8 |

[1] See Figure 1 for locations of stations.

stated that the siscowet differs in no technical respect from ordinary lake trout, is connected with the latter by perfect intergradations known locally as half-breeds, and that, "There is every reason to believe that the siscowet is an ordinary trout which has fed on these soft fat fishes [deep-water ciscoes] and which has followed them into deep water." Eddy and Surber (1947) also treated the siscowet as a subspecies, but believed that it probably hybridizes with the lake trout, since ". . . all sorts of gradations in body form occur." Hubbs and Lagler (1958) retained the subspecific classification provisionally, "... pending a determination of whether or not the characters are genetically fixed."

Collections from Lake Superior in 1948–56 provided extensive data for the comparison of the length–weight relation of lake trout and siscowets (as identified by experienced commercial fishermen; siscowet as used here includes half-breeds). When large differences in fat content were found among flesh samples collected from the two forms in 1953,[2] further samples were collected to make possible the more detailed comparisons given here. The following sections include comparisons of percentage fat in the flesh of native and hatchery-reared siscowets and lake trout; records of iodine numbers of the fat of the two forms; and a study of the correlation between fat content and fish weight. Data are presented also for distinctive subpopulations of lake trout from Lake Superior and Green Lake, Wisconsin.

## MATERIALS AND METHODS

The dates, localities, and depths of collection of 67 siscowets and 46 lake trout from which flesh samples were taken for analysis are given in Table 1 (see also Figure 1). In addition to a few siscowets and lake trout collected in 1953, 60 siscowets were purchased from commercial fishermen in 1954, and lake trout were added to the series as opportunity afforded in 1954–61. Still other flesh samples, from fish with sufficiently distinctive characteristics to warrant separate consideration, came from Lake Superior, from hatchery stocks, and from Green Lake, Wisconsin.

Most samples of flesh were taken from the middorsal region. The sample was removed by making two transverse incisions, one anterior and one posterior to the dorsal fin, and a longitudinal incision near the junction of the ribs and vertebral column. Since each sample weighed about ¼ to ½ pound, the length of the section excised depended on the size of the fish; among the smaller individuals, it extended from the nape to the caudal peduncle. Twelve samples from siscowets were taken as transverse sections through the middle of the entire fish, including the ribs

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[2] Eschmeyer, Paul H. (1954) Lake trout investigations. Great Lakes Fishery Committee, Minutes of annual meeting, St. Louis, Missouri, pp. 41–44. (Mimeo.)

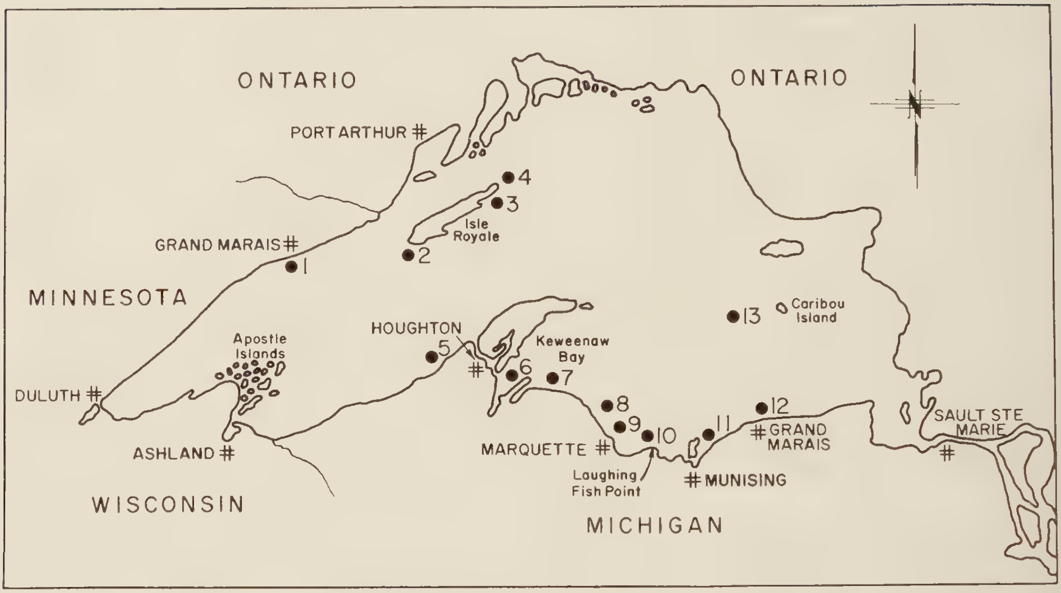

FIGURE 1.—Collecting stations for Lake Superior siscowets and lake trout used for chemical analysis.

but excluding the viscera. Although samples taken from different portions of the body of siscowets and lake trout have been demonstrated to contain different quantities of fat (Thurston, 1962), these minor differences among flesh samples did not significantly influence the results in the present study.

The flesh samples were preserved individually in 10 per cent formalin; before analysis, this liquid was evaporated to a small volume in a steam bath and returned to the sample. After the skin and dorsal fin had been removed, the sample was ground and dried in a vacuum to constant weight. The fat was then removed by continuous ethyl–ether extraction for 16 hours, with a commercial model of a Bailey–Walker apparatus (Walker and Bailey, 1914), and following the general methods of the Association of Official Agricultural Chemists (1960). Analyses were determined in terms of both dry and moist weight. Most reliance was placed on the water-free values, however, and these are used in the text unless otherwise indicated. Percentage water is given in most tables to complete the presentation of data, but it is not discussed. Iodine numbers of fat were determined by the method of Hanus (Association of Official Agricultural Chemists, 1960). All values for fat content and iodine number are averages of duplicate analyses. The analytical work was carried out in the Eastern Fish Nutrition Laboratory, U. S. Bureau of Sport Fisheries and Wildlife, Cortland, New York.

Data for comparison of the length–weight relation of siscowets and lake trout were provided by 393 siscowets and 3,284 lake trout taken in Lake Superior by commercial fishermen or by the research vessel *Cisco*, in 1948–56. The siscowets came from widely scattered localities, but more than three-fourths were collected near Marquette, Michigan. Most of the lake trout were from State of Michigan waters. About half were taken near Marquette; a few were collected as far west as the Apostle Islands region of Wisconsin. The lake trout are believed to be closely representative of the population of lean lake trout in southern Lake Superior during the years of collection (some aspects of their life history were described by Eschmeyer, 1955). All of the siscowets and about 80 per cent of the lake trout were caught in gill nets (1- to 6-inch mesh, extension measure); other lake trout were taken in trawls (11 per cent), in impounding nets (6 per cent), or on set hooks (3 per cent). About 89 per cent of the siscowets and 87 per cent of the lake trout were

TABLE 2.—*Percentage fat and water in the flesh of siscowets and lake trout from Lake Superior, 1953–61*

| Total length (inches) | | Number of fish | Average weight (pounds)[1] | Percentage water | Percentage fat | |
|---|---|---|---|---|---|---|
| Interval | Average | | | | Dry weight | Wet weight |
| Siscowets | | | | | | |
| 11.0–12.9 | 11.8 | 1 | 0.6 | 70.0 | 32.5 | 9.8 |
| 13.0–14.9 | 14.0 | 2 | — | 65.2 | 44.1 | 15.4 |
| 15.0–16.9 | 16.3 | 9 | 1.8 | 60.7 | 52.9 | 21.2 |
| 17.0–18.9 | 17.9 | 22 | 2.3 | 59.8 | 55.6 | 22.5 |
| 19.0–20.9 | 20.0 | 13 | 3.5 | 54.7 | 64.1 | 29.4 |
| 21.0–22.9 | 22.3 | 5 | 4.7 | 54.8 | 63.9 | 29.0 |
| 23.0–24.9 | 24.0 | 2 | 9.3 | 60.2 | 66.6 | 26.8 |
| 25.0–26.9 | 25.6 | 3 | 7.8 | 45.5 | 69.7 | 38.2 |
| 27.0–28.9 | 28.1 | 4 | 10.8 | 44.7 | 73.9 | 41.5 |
| 29.0–30.9 | 29.8 | 2 | 12.8 | 45.7 | 81.0 | 43.8 |
| 31.0–32.9 | 31.8 | 4 | 16.8 | 41.8 | 82.8 | 48.1 |
| Lake trout | | | | | | |
| 9.0–10.9 | 10.5 | 5 | 0.3 | 76.8 | 10.2 | 2.4 |
| 11.0–12.9 | 11.5 | 11 | 0.4 | 76.1 | 13.6 | 3.3 |
| 13.0–14.9 | 13.6 | 2 | 0.7 | 72.8 | 13.8 | 3.8 |
| 15.0–16.9 | 16.0 | 5 | 1.2 | 70.6 | 16.3 | 4.8 |
| 17.0–18.9 | 18.0 | 4 | 1.7 | 71.3 | 18.9 | 5.4 |
| 19.0–20.9 | 19.9 | 4 | 2.4 | 66.4 | 23.4 | 7.9 |
| 21.0–22.9 | 22.1 | 4 | 3.4 | 71.4 | 22.7 | 6.5 |
| 25.0–26.9 | 25.0 | 1 | 5.2 | 64.7 | 26.8 | 9.5 |
| 27.0–28.9 | 28.4 | 2 | 7.0 | 66.6 | 31.8 | 10.6 |
| 29.0–30.9 | 29.6 | 2 | 8.5 | 63.6 | 38.4 | 14.0 |
| 31.0–32.9 | 31.6 | 2 | 8.8 | 55.2 | 37.9 | 17.0 |
| 35.0–36.9 | 35.5 | 2 | — | 69.2 | 38.4 | 11.8 |
| 37.0–38.9 | 37.6 | 2 | — | 57.2 | 43.6 | 18.9 |

[1] Fish of the length classes for which weight is not shown were not weighed; one fish was not weighed in each of four length classes of siscowets (15.0–16.9, 17.0–18.9, 21.0–22.9, and 23.0–24.9 inches), and two length classes of lake trout (29.0–30.9 and 31.0–32.9 inches).

collected in June–October. The series included few fish in spawning condition.

## FAT CONTENT OF NATIVE SISCOWETS AND LAKE TROUT FROM LAKE SUPERIOR

### *Percentage fat*

The fat content of the flesh of native siscowets from Lake Superior varied over the wide range of 32.5 to 88.8 per cent.[3] For lake trout the range was 6.6 to 52.3 per cent. The percentage fat in both forms increased progressively with increasing length (Thurston, 1962, observed a similar relationship for siscowets) and was markedly higher for siscowets than for lake trout at all comparable lengths, without exception. Average percentages of fat of siscowets by 2-inch length groups ranged from 32.5 in the 11.0- to 12.9-inch group (one fish) to 82.8 at 31.0–32.9 inches; for lake trout the values extended from 10.2 per cent at 9.0–10.9 inches to 43.6 per cent at 37.0–38.9 inches (Table 2).

The rate of increase in fat content with increasing length was markedly greater for siscowets than for lake trout among the smaller fish (Figure 2). The curve for siscowets extends from a fat content of about 33 per cent at a length of 12 inches to 63 per cent at 20 inches (an increase of 3.7 percentage points per inch of length), to 75 per cent at 26 inches (2.0 percentage points per inch) to 83 per cent at 32 inches (an increase of 1.3 percentage points per inch). For lake trout, a reasonably adequate fit to the scattered points was given by a straight line extending from a fat content of about 10 per cent at 10 inches to 44 per cent at 38 inches (an increase of about 1.2 percentage points per 1-inch increase in length). In contrast to the sharp divergence of the two curves at the shorter lengths, the rate of increase in fat content thus was nearly equal for the two forms at lengths greater than 26 inches. The average difference in fat indicated by the two curves is about 20 percentage points at 12 inches, 40 at 20 inches, and 46 points at 32 inches.

The widely scattered points of Figure 2 show that individual variation in fat content

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[3] The percentage was outside this range in one extraordinarily fat siscowet, for which data are incomplete (no length measurement) and which accordingly was not included in the listing of Table 1. The dressed weight of the fish was 11.5 pounds (estimated round weight and total length, 13.5 pounds and 30 inches). The fat content was 92.5 per cent (69.8 per cent, wet weight).

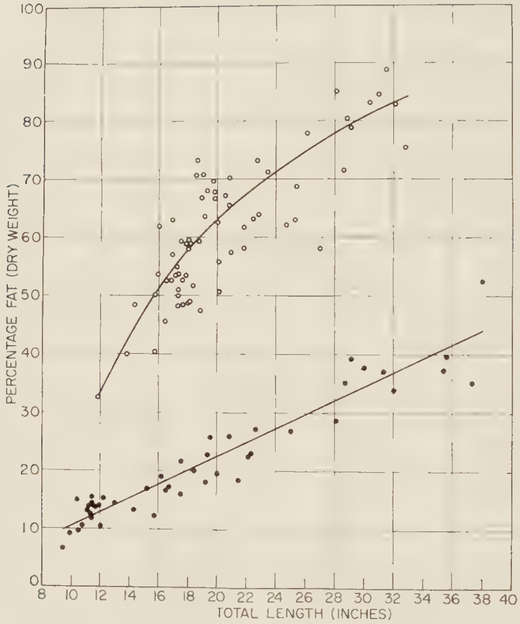

FIGURE 2.—Percentage fat in the flesh of Lake Superior siscowets (open circles) and lake trout (solid circles) of different lengths. Each circle represents one fish. The curves were fitted by inspection.

among siscowets was great. Two siscowets, 18.6 and 18.8 inches long, had fat contents of 73.2 and 47.3 per cent; two others, 27.0 and 28.1 inches long, had 58.8 and 85.0 per cent. This latter difference of more than 26 percentage points was greater than the difference between this 27.0-inch siscowet and a 29.1-inch lake trout, which had a fat content of 39.1 per cent. Nevertheless, the plotted data clearly reveal its affinity to siscowets rather than to lake trout; it is about 18 percentage points removed from the curve for siscowets, and about 27 percentage points from the curve for lake trout. The maximum difference in percentage fat of lake trout of similar size was between the two largest fish in the series—a 37.3-inch fish with 35.0 per cent fat and a 38.0-inch fish with 52.3 per cent. The variability in fat content within each group does not detract from the general conclusion that the two forms are totally distinct.[4]

Although the fat content of certain Salmonidae has been shown to vary with season and sex (Morawa, 1960), detailed examination of our data excluded the possibility that the large differences in fat content between siscowets and lake trout were in any way the result of seasonal or annual variations, sex or maturity, geographic locality of collection, or minor differences in the manner in which flesh samples were removed from the fish.

Thurston (1962) reported oil contents (wet-weight basis) of 21.3 to 67.2 per cent in fillets of 29 *siscowet* from Lake Superior and 1.9 to 22.5 per cent in fillets of 23 *namaycush*. The fillets of one series of 10 *siscowet*, 54 to 69 cm long, fork length, yielded 21.3 to 67.2 per cent oil; and fillets of 5 *namaycush*, 35 to 49 cm long, contained 9.1 to 22.5 per cent. The *namaycush* series therefore must have included one fish 49 cm long or less with a higher oil content than a siscowet 54 cm long or longer; thus, in contrast to the wide difference in fat content of siscowets and lake trout at all similar lengths in our series, the percentages of oil overlapped in the two forms in his collections. A fork length of 49 cm (about 21 inches, total length) or less and an oil content of 22.5 per cent (wet weight) would place his *namaycush* within the range of variation of our siscowets and far outside the range of our lake trout of comparable length (Table 2). Despite differences in analytical technique in the two studies, we believe, in the light of our larger series of samples, that at least one of the *namaycush* sent to him for analysis was mislabeled.

### *Iodine number of fat of siscowets and lake trout*

The iodine number (an empirical index of fat hardness, commonly used in classifying the saturation of oils; the number varies inversely as the melting point) ranged from 100 to 160 among siscowets and from 103 to 161 among lake trout. Despite the similarity of these extremes, the iodine number of the fat of siscowets was lower than that for lake trout in fish of five of six length classes for which comparable data were available (Table 3). The trend among siscowets was toward a decreasing iodine number with increase in length and fat content. The average iodine numbers of siscowets declined progressively, from 134 at 9.0–12.9 inches to 109 at 29.0–32.9 inches. The rate of decline was relatively uniform for length groups shorter than 25 inches, but was accelerated sharply among larger siscowets. The iodine number of the fat of six fish in the 29.0- to 32.9-inch group ranged only from 100 to 116.

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[4] Many fish collected for fat analysis were classified only as siscowets or lean lake trout, without further differentiation of the siscowets into fats and half-breeds. The possibility that half-breeds (which perhaps might be expected to have a fat content intermediate between siscowets and lean lake trout) were not fully represented in the samples was precluded, however, by the division of the largest sample in the series—40 siscowets collected 28 September 1954 (see Table 1)—into subgroups by the commercial fisherman who caught them. He identified 32 half-breeds and 8 fats. Of these, 19 half-breeds and 5 fats had a lower fat content than that suggested by the curve for siscowets shown in Figure 2, and the remainder (except for one half-breed exactly on the curve) had a higher fat content.

The iodine numbers of the fat of lake trout varied widely in relation to length and fat content. Although the change in iodine number with increasing length appeared to be downward, the trend was far from clear (Table 3). The average iodine number for 28 lake trout, 9.4–22.3 inches long, was 140; for 11 lake trout 25.0–38.0 inches long it was 127.

### *Relation of fat content to relative heaviness*

The average weight of siscowets from Lake Superior exceeded that of lake trout at all lengths, and the difference in weight increased progressively with increasing length (Table 4, Figure 3). The curves of Figure 3 were derived by fitting straight lines to the logarithms of the average lengths and weights of 393 siscowets and 3,284 lake trout, grouped in ½-inch intervals of length. The equation for the siscowets is:

$$\text{Log } W = -3.890 + 3.387 \text{ Log } L,$$

where $W$ = weight in pounds and $L$ = total length in inches. The equation for lake trout is:

$$\text{Log } W = -3.765 + 3.191 \text{ Log } L.$$

The weight of siscowets increased as the 3.387 power of the length, and the weight of lake trout as the 3.191 power. The calculated weight of siscowets exceeded that of lake trout by about ½ pound at 17.5 inches, 1 pound at 21 inches, 3 pounds at 28 inches, and 5 pounds at 32 inches.

The length–weight data were the basis for an evaluation of the relation of percentage fat to relative weight. Correlation coefficients

TABLE 3.—*Numbers of Lake Superior siscowets and lake trout with fat of different iodine numbers*

| Total length (inches) | Iodine number | | | | |
|---|---|---|---|---|---|
| | 100–119 | 120–139 | 140–159 | 160–169 | Average |
| Siscowets | | | | | |
| 9.0–12.9 | — | 1 | — | — | 134 |
| 13.0–16.9 | 1 | 8 | 2 | — | 132 |
| 17.0–20.9 | 7 | 21 | 6 | 1 | 130 |
| 21.0–24.9 | 2 | 4 | 1 | — | 128 |
| 25.0–28.9 | 2 | 5 | — | — | 122 |
| 29.0–32.9 | 6 | — | — | — | 109 |
| Total or average | 18 | 39 | 9 | 1 | 127 |
| Lake trout[1] | | | | | |
| 9.0–12.9 | 1 | 5 | 10 | — | 140 |
| 13.0–16.9 | 1 | 3 | 2 | 1 | 138 |
| 17.0–20.9 | — | 1 | 3 | — | 144 |
| 21.0–24.9 | — | 1 | — | — | 137 |
| 25.0–28.9 | 2 | 1 | — | — | 113 |
| 29.0–32.9 | 1 | 2 | 1 | — | 128 |
| 33.0–36.9 | — | 1 | 1 | — | 135 |
| 37.0–38.9 | — | 2 | — | — | 136 |
| Total or average | 5 | 16 | 17 | 1 | 136 |

[1] Iodine numbers were not determined for seven lake trout.

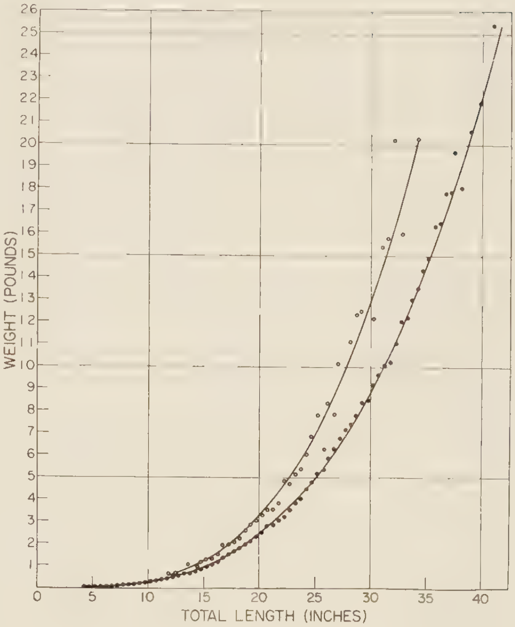

FIGURE 3.—Length–weight relationship of siscowets and lake trout from Lake Superior. The open circles and solid dots represent the empirical data for siscowets and lake trout, respectively. The curves are based on equations given in the text.

were computed between the percentage deviations of individual weight and percentage fat of 61 siscowets and 40 lake trout from the curves for each respective form in Figures 2 and 3. Neither coefficient was significant. Thus a siscowet or lake trout that was heavier or lighter than average did not tend to have a correspondingly higher or lower fat content.

TABLE 4.—*Length–weight relation of siscowets and lake trout from Lake Superior*

[Total number of fish: 393 siscowets; 3,284 lake trout]

| Total length (inches) | Siscowets | | | Lake trout | | |
|---|---|---|---|---|---|---|
| | Number of fish | Weight (pounds) | | Number of fish | Weight (pounds) | |
| | | Actual | Calculated[1] | | Actual | Calculated[1] |
| 4.0– 4.4 | — | — | — | 33 | 0.02 | 0.02 |
| 4.5– 4.9 | — | — | — | 36 | 0.02 | 0.02 |
| 5.0– 5.4 | — | — | — | 46 | 0.03 | 0.03 |
| 5.5– 5.9 | — | — | — | 52 | 0.05 | 0.04 |
| 6.0– 6.4 | — | — | — | 82 | 0.06 | 0.06 |
| 6.5– 6.9 | — | — | — | 130 | 0.08 | 0.07 |
| 7.0– 7.4 | — | — | — | 102 | 0.09 | 0.09 |
| 7.5– 7.9 | — | — | — | 78 | 0.11 | 0.12 |
| 8.0– 8.4 | — | — | — | 84 | 0.14 | 0.14 |
| 8.5– 8.9 | — | — | — | 49 | 0.17 | 0.17 |
| 9.0– 9.4 | — | — | — | 39 | 0.20 | 0.20 |
| 9.5– 9.9 | — | — | — | 53 | 0.24 | 0.24 |
| 10.0–10.4 | — | — | — | 74 | 0.27 | 0.28 |
| 10.5–10.9 | — | — | — | 64 | 0.32 | 0.33 |
| 11.0–11.4 | — | — | — | 63 | 0.37 | 0.38 |
| 11.5–11.9 | 1 | 0.60 | 0.55 | 58 | 0.43 | 0.44 |
| 12.0–12.4 | — | — | — | 79 | 0.49 | 0.50 |
| 12.5–12.9 | 1 | 0.70 | 0.67 | 77 | 0.55 | 0.57 |
| 13.0–13.4 | — | — | — | 74 | 0.64 | 0.65 |
| 13.5–13.9 | 3 | 1.07 | 0.89 | 75 | 0.70 | 0.73 |
| 14.0–14.4 | 1 | 1.00 | 1.08 | 68 | 0.78 | 0.81 |
| 14.5–14.9 | 5 | 1.18 | 1.16 | 56 | 0.87 | 0.92 |
| 15.0–15.4 | 4 | 1.29 | 1.27 | 54 | 0.97 | 1.01 |
| 15.5–15.9 | 9 | 1.35 | 1.45 | 65 | 1.07 | 1.13 |
| 16.0–16.4 | 9 | 1.56 | 1.61 | 55 | 1.21 | 1.24 |
| 16.5–16.9 | 12 | 1.94 | 1.78 | 45 | 1.35 | 1.37 |
| 17.0–17.4 | 19 | 1.99 | 1.97 | 60 | 1.49 | 1.51 |
| 17.5–17.9 | 25 | 2.10 | 2.17 | 82 | 1.63 | 1.65 |
| 18.0–18.4 | 35 | 2.29 | 2.39 | 59 | 1.80 | 1.80 |
| 18.5–18.9 | 36 | 2.64 | 2.62 | 68 | 1.96 | 1.97 |
| 19.0–19.4 | 43 | 2.89 | 2.86 | 76 | 2.11 | 2.14 |
| 19.5–19.9 | 35 | 3.08 | 3.12 | 84 | 2.34 | 2.32 |
| 20.0–20.4 | 25 | 3.34 | 3.40 | 107 | 2.50 | 2.51 |
| 20.5–20.9 | 26 | 3.57 | 3.69 | 83 | 2.78 | 2.72 |
| 21.0–21.4 | 10 | 3.59 | 4.00 | 94 | 2.87 | 2.93 |
| 21.5–21.9 | 15 | 3.86 | 4.33 | 92 | 3.09 | 3.16 |
| 22.0–22.4 | 7 | 4.85 | 4.68 | 52 | 3.24 | 3.40 |
| 22.5–22.9 | 10 | 4.73 | 5.04 | 45 | 3.53 | 3.64 |
| 23.0–23.4 | 8 | 5.17 | 5.43 | 36 | 3.84 | 3.91 |
| 23.5–23.9 | 7 | 5.40 | 5.84 | 30 | 4.03 | 4.19 |
| 24.0–24.4 | 8 | 6.07 | 6.26 | 19 | 4.47 | 4.47 |
| 24.5–24.9 | 4 | 6.87 | 6.62 | 35 | 4.78 | 4.78 |
| 25.0–25.4 | 5 | 7.84 | 7.19 | 23 | 5.15 | 5.09 |
| 25.5–25.9 | 6 | 6.29 | 7.78 | 20 | 5.38 | 5.42 |
| 26.0–26.4 | 6 | 8.37 | 8.09 | 23 | 5.84 | 5.77 |
| 26.5–26.9 | 3 | 7.87 | 8.74 | 28 | 6.28 | 6.12 |
| 27.0–27.4 | 2 | 10.15 | 9.08 | 28 | 6.78 | 6.50 |
| 27.5–27.9 | — | — | — | 35 | 7.17 | 6.89 |
| 28.0–28.4 | 3 | 11.13 | 10.39 | 46 | 7.40 | 7.29 |
| 28.5–28.9 | 2 | 12.35 | 11.16 | 49 | 7.76 | 7.71 |
| 29.0–29.4 | 1 | 12.50 | 11.70 | 28 | 8.36 | 8.15 |
| 29.5–29.9 | — | — | — | 44 | 8.54 | 8.60 |
| 30.0–30.4 | 2 | 12.19 | 13.26 | 37 | 9.16 | 9.07 |
| 30.5–30.9 | — | — | — | 35 | 9.64 | 9.56 |
| 31.0–31.4 | 1 | 15.40 | 14.49 | 28 | 10.08 | 10.07 |
| 31.5–31.9 | 1 | 15.80 | 15.30 | 22 | 10.23 | 10.59 |
| 32.0–32.4 | 1 | 20.20 | 16.31 | 20 | 11.08 | 11.13 |
| 32.5–32.9 | 1 | 16.00 | 17.54 | 16 | 12.05 | 11.69 |
| 33.0–33.4 | — | — | — | 22 | 12.23 | 12.27 |
| 33.5–33.9 | — | — | — | 11 | 13.02 | 12.87 |
| 34.0–34.4 | 1 | 20.30 | 20.21 | 12 | 13.54 | 13.41 |
| 34.5–34.9 | — | — | — | 10 | 14.33 | 14.13 |
| 35.0–35.4 | — | — | — | 9 | 14.89 | 14.79 |
| 35.5–35.9 | — | — | — | 7 | 16.34 | 15.47 |
| 36.0–36.4 | — | — | — | 5 | 16.48 | 16.17 |
| 36.5–36.9 | — | — | — | 2 | 17.81 | 16.90 |
| 37.0–37.4 | — | — | — | 4 | 17.86 | 17.64 |
| 37.5–37.9 | — | — | — | 2 | 19.68 | 18.26 |
| 38.0–38.4 | — | — | — | 2 | 18.07 | 19.04 |
| 39.0 | — | — | — | 1 | 20.60 | 20.52 |
| 39.8 | — | — | — | 1 | 21.90 | 21.89 |
| 41.0 | — | — | — | 1 | 25.40 | 24.06 |

[1] See text for formulas for calculated weight.

### *Fat content of lake trout of distinctive subpopulations*

The names "humper" and "humpy" are among the more common given by commercial fishermen to certain subpopulations of lake trout which usually are caught during their spawning period, when they congregate on or near certain reefs or "humps" in Lake Superior. These fish commonly reach maturity at relatively short lengths (13 to 16 inches), do not reach a great length (probably seldom exceed 25 inches), spawn principally in late September (known spawning grounds are southeast of Isle Royale and west of Caribou Island), have thin abdominal walls (one common name is "paperbelly"), and flesh that usually is pink or red. The appearance is sufficiently distinctive (color of fins, shape of head, general contours of body) to permit experienced commercial fishermen to separate them with reasonable accuracy from siscowets or typical lake trout, at least immediately preceding and during the spawning season. Fishermen describe the smaller sizes of humpers as similar to lean lake trout and the larger sizes as "rather fat." Humpers sometimes have been sold as lean lake trout when the market demand was high, but at other times have been grouped with siscowets and sold as half-breeds.

The present data are restricted to a series of 11 humpers, 11.6 to 20.4 inches long, collected on 28 August 1959, southeast of Isle Royale (Station 3, Figure 1), at a depth of 34 to 45 fathoms. The group included three males and eight females; the smallest, largest, and one other fish were immature, but eight were mature and presumably would have spawned in September. Weights of most of the fish were intermediate between the weights of siscowets and lake trout of the same length.

The percentage fat of the humpers was much nearer to that of lake trout of comparable length than to siscowets, but the increase in fat with increase in length was more rapid than for lake trout, and nearly as rapid as for siscowets. The percentage fat ranged from 7.3 to 30.6; the lowest and highest fat contents were in the shortest and longest fish (Table 5). The smallest humper had a slightly lower fat content than our lake trout of similar size, three fish were closely similar to lake trout, and the remaining seven had higher percentages of fat. Fish of the latter group were 15.2 to 20.4 inches long and had fat contents within the narrow range of 23.1 to 30.6 per cent (average 27.8). A plot of the data for the humpers (Figure 4) indicated a straight line extending from a fat content of 10 per cent at 12 inches (slightly below that of lean trout) to about 31 per cent at 19 inches (about 10 percentage points higher than the average for lean trout, but 29 points lower than the average for siscowets); fat increased at the rate of 3.0 percentage points per inch of length, or more than double the average rate of 1.2 for lake trout, but less than the rate of 3.9 for siscowets within this length range. These limited data suggest that the percentage fat and rate of change of fat content with increasing length are different for humpers than for either siscowets or typical lean lake trout.

Flesh samples were taken from five lake trout collected at four widely scattered locali-

TABLE 5.—*Percentages fat and water in the flesh of a subpopulation of "humper" lake trout collected near Isle Royale, Lake Superior, 28 August 1959, and a comparison with average fat content of Lake Superior siscowets and lean lake trout*

| Total length (inches) | Weight (pounds) | Percentage water | Percentage fat (dry weight) | | |
|---|---|---|---|---|---|
| | | | Humper | Lean lake trout[1] | Siscowet[1] |
| 11.6 | 0.6 | 77.9 | 7.3 | 12.4 | — |
| 13.6 | 0.8 | 71.5 | 16.3 | 14.8 | 41.2 |
| 15.2 | 1.2 | 67.6 | 23.1 | 16.7 | 48.2 |
| 15.3 | 1.0 | 74.9 | 16.3 | 16.8 | 48.6 |
| 15.7 | 1.4 | 68.5 | 28.4 | 17.3 | 50.1 |
| 15.9 | 1.3 | 75.7 | 16.6 | 17.5 | 50.9 |
| 16.5 | 1.5 | 71.5 | 28.9 | 18.3 | 53.0 |
| 17.9 | 2.1 | 69.1 | 27.3 | 20.0 | 57.7 |
| 18.1 | 2.2 | 66.7 | 25.9 | 20.2 | 58.2 |
| 18.8 | 2.3 | 67.7 | 30.5 | 21.1 | 60.0 |
| 20.4 | 3.6 | 59.6 | 30.6 | 22.9 | 64.0 |

[1] Values for siscowets and lean lake trout are from the curves of Figure 2.

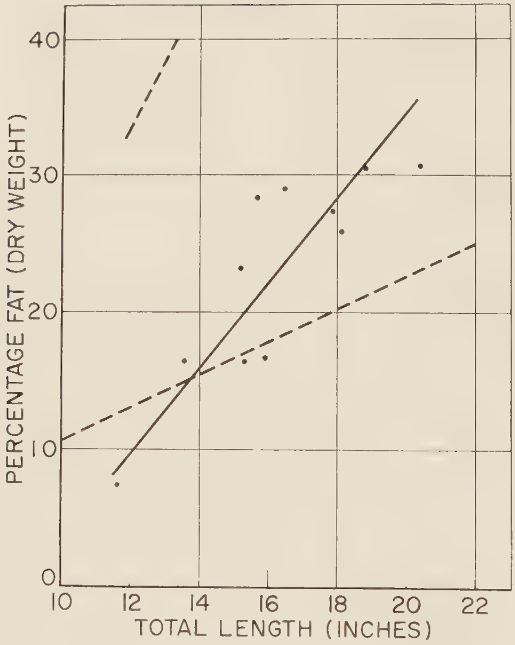

FIGURE 4.—Percentage fat in the flesh of a subpopulation of "humper" lake trout from Lake Superior. Dots represent individual fish; the solid line was fitted by inspection. The broken lines are for siscowets (upper) and lake trout (lower), from Figure 2.

ties in Lake Superior (Stations 1, 5, 12, and 13—see Figure 1), whose possible relationship to other fish of the present series was not recognized at the time of collection, and which are not considered elsewhere in this paper. The fish were 17.7 to 20.4 inches long, and the weight of each was intermediate between the means for siscowets and lake trout of the same length. The percentage fat was within the narrow limits of 27.9 to 33.0—far below the average for siscowets, and above the average (and outside the range of variation) for lean lake trout of similar length, but closely comparable to the percentage in humpers. These fish of uncertain relationship probably were humpers or a closely related form.

Three fish were collected from a distinctive subpopulation of siscowets[5] which spawn in the late spring. They were in spawning condition when caught on 8 June 1953, in gill nets set in 8 to 15 fathoms, east of Isle Royale (Station 4, Figure 1). The fish were 19.4 to 23.4 inches long, and had fat contents of 55.8 to 64.2 per cent (well within the range of variation of other siscowets of comparable length) and iodine numbers of 114 to 130.

### FAT CONTENT OF HATCHERY-REARED SISCOWETS, HYBRIDS, AND LAKE TROUT OF KNOWN PARENTAGE

The consistently higher fat content of siscowets than of lake trout demonstrated in the preceding sections and the differences in seasons, depths, and localities of spawning suggest that the two forms are genetically distinct. It is possible, on the other hand, that diet and environment contribute importantly to the differences in fat. Diet has a pronounced effect on the fat content of hatchery-reared brook trout (Phillips et al., 1952) and was suggested as the reason for the difference between siscowets and lake trout by Jordan and Evermann (1911); environmental factors have been shown to influence the percentage fat in certain coregonines (Morawa, 1958). Opportunities for comparisons in which these factors were more closely controlled were provided by stocks of hybrids (lake trout × siscowet), siscowets, and lake trout hatched from eggs collected by commercial fishermen in Lake Superior and reared under nearly identical conditions in ponds of the State of Michigan Fish Hatchery at Marquette. Parents of the hybrids (an 11-pound female siscowet and an 8-pound male lake trout) were taken near Marquette in 1952, parents of the siscowets near Isle Royale in 1958, and parents of the lean lake trout near Marquette in 1952 and 1957.

Flesh samples for chemical analyses were taken from 9 hybrids in October 1956 and 8 in August 1959, and from 5 hybrids and 10 siscowets in October 1961. On the dates of collection, flesh samples were taken also from equal numbers of lean lake trout from lots with a length range closely similar to that of the hybrids and siscowets. In the collection of flesh samples, the fish were crowded with a seine toward one end of a rearing pond and

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[5] These fish sometimes also are called humpers or "humpies" by commercial fishermen (Eschmeyer, 1955), but the fat analyses clearly identify them as siscowets.

TABLE 6.—*Percentage fat (dry weight) in the flesh of hatchery-reared lake trout, hybrids (lake trout × siscowet), and siscowets, and a comparison with average fat content of Lake Superior lake trout and siscowets*

| Length interval (inches) | Hatchery-reared[1] | | | Native[2] | |
|---|---|---|---|---|---|
| | Siscowet | Hybrid | Lake trout | Siscowet | Lake trout |
| 13.0–13.9 | 23.5<br>(4) | — | 11.8<br>(2) | 40.7 | 14.7 |
| 14.0–14.9 | 25.0<br>(4) | — | 12.2<br>(3) | 45.2 | 15.9 |
| 15.0–15.9 | 26.8<br>(2) | 19.0<br>(4) | 12.3<br>(9) | 49.3 | 17.1 |
| 16.0–16.9 | — | 20.5<br>(4) | 15.2<br>(4) | 53.0 | 18.3 |
| 17.0–17.9 | — | 17.7<br>(1) | 17.9<br>(1) | 56.6 | 19.5 |
| 20.0–20.9 | — | — | 17.4<br>(4) | 64.2 | 23.1 |
| 21.0–21.9 | — | 29.8<br>(2) | 18.4<br>(3) | 66.5 | 24.3 |
| 22.0–22.9 | — | 32.6<br>(2) | 22.3<br>(1) | 68.5 | 25.5 |
| 23.0–23.9 | — | 26.0<br>(4) | — | 70.3 | 26.7 |
| 24.0–24.9 | — | 36.6<br>(2) | 32.8<br>(1) | 72.1 | 27.8 |
| 25.0–25.9 | — | — | 25.0<br>(3) | 73.8 | 29.0 |
| 26.0–27.0 | — | 41.0<br>(3) | 33.1<br>(1) | 75.5 | 30.2 |

[1] Numbers of fish are shown in parentheses. Percentage water ranged from 64.6 to 73.8 among different length classes of siscowets, 56.5 to 66.8 among hybrids, and 56.7 to 70.9 among lake trout.

[2] Values for native fish are from the curves of Figure 2, for lengths at the midpoint of the interval.

then a hand net was plunged into their midst to obtain the specimens for analysis.

Differences in percentage fat among the groups of hatchery-reared fish and between hatchery-reared and native fish are apparent in the tabulation of data for fish of the several categories by 1-inch intervals of length (Table 6). Evaluation of the differences is complicated, however, by the strong tendency in all groups for percentage fat to increase with length, and by differences in the range of lengths of fish available for comparison from each group. Relative fat content of fish of the various groups is shown more clearly when data are restricted to the average values for the length groups in which each of the forms being compared are represented (Table 7), or by plotting the fat content for each fish against total length (Figure 5). It then becomes clear that both hatchery-reared lake trout and siscowets tend to have considerably less fat than native Lake Superior fish of the respective forms. The interpretation of relations among hatchery fish should, therefore, be restricted to these groups alone, without reference to native fish.

Among the hatchery-reared fish, siscowets had a far higher percentage fat than either hybrids or lean lake trout; percentages for individual siscowets did not overlap those for either of the other groups. The shortest siscowet (13.3 inches) had a higher fat content than any hybrid through the length of 16.5 inches or any lake trout through 20.3 inches. The average fat content of hybrids was higher than that of lake trout at all lengths (except in

TABLE 7.—*Average percentage fat in different combinations of 1-inch length classes of hatchery-reared siscowets, hybrids, and lake trout, compared with native Lake Superior siscowets and lake trout.*

[Averages are based only on the 1-inch length intervals (from Table 6) in which each of the forms being compared is represented.]

| Categories compared | Number of length classes | Hatchery-reared | | | Native | |
|---|---|---|---|---|---|---|
| | | Siscowet | Hybrid | Lake trout | Siscowet | Lake trout |
| All categories | 1 | 26.8 | 19.0 | 12.3 | 49.3 | 17.1 |
| Hatchery and native siscowets and lake trout | 3 | 25.1 | — | 12.1 | 45.1 | 15.9 |
| Hatchery hybrids and lake trout, and native siscowets and lake trout | 7 | — | 28.2 | 21.7 | 63.1 | 23.2 |
| Hatchery lake trout, and native siscowets and lake trout | 11 | — | — | 19.9 | 60.5 | 22.3 |

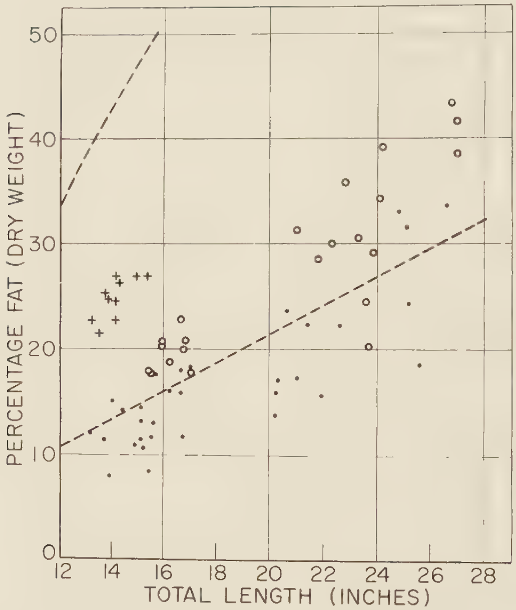

FIGURE 5.—Percentage fat in the flesh of hatchery-reared lake trout (dots), lake trout X siscowet hybrids (open circles), and siscowets (crosses). The broken lines are for native Lake Superior lake trout (lower) and siscowets (upper), from Figure 2.

the poorly represented 17.0- to 17.9-inch group of Table 6), despite overlap among individuals (Figure 5).

The data for hatchery-reared fish[6] demonstrate that the differences in fat content between native siscowets and lake trout persist in hatchery stocks; the relation of fat content of the hybrids to that of the parent stocks is about as might be expected if it is assumed that the differences between the parent forms are genetic.

The evidence of a genetic difference between the parent stocks is convincing if it is assumed that a difference in density of fish in the several rearing ponds did not influence the results. Throughout their period of captivity, the groups of fish compared were kept in separate rearing enclosures of practically identical area, depth, and water flow, and were fed the same food. The only known difference in rearing conditions was the somewhat greater density of lake trout than of hybrids and siscowets in the ponds from which samples were taken. The different ponds contained, for example, 383 hybrids and 500 lake trout when the first sample of hybrids was collected, and 290 siscowets and about 500 lake trout when the sample of siscowets was collected. We have seen no records of any effect of density of fish in rearing ponds on fat content of the flesh, but believe that any possible biasing effect was minimized by the prevailing hatchery practice of adjusting the quantity of food fed to the weight of the fish in each pond. We do not believe, therefore, that effects of population density in the ponds detract from the general conclusion that real differences in fat content exist between siscowets and lake trout.

## FAT CONTENT OF LAKE TROUT FROM GREEN LAKE, WISCONSIN

The lake trout population of Green Lake, Wisconsin, was described by Hacker (1957) as consisting entirely of planted fish of two separate stocks, one originating from Lake Superior and the other, composed entirely of fish 9 or more years old at the time of collection, probably from Lake Michigan. Additional later observations suggested that the older (Lake Michigan) fish appeared to be divided into subpopulations. Hacker described (personal communication) the fish of one of these subpopulations as dark-colored, with bright orange and white fins, and with a thin ventral body wall; fish of the other group were light-colored and had pale fins and a thick ventral body wall. Fish of the two groups spawned on different dates. Flesh samples were analyzed from six fish collected in November 1953 and two in December 1959 to determine whether fat content differed significantly. The fish sampled in 1953 were taken without regard to relationship to the group represented, but the fish collected in 1959 were selected to include one typical fish of each form.

The eight fish from Green Lake were readily divisible into two groups on the basis of fat

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[6] Iodine numbers of the fat of hybrids and lake trout were closely similar in the 1956 collection (no data for subsequent collections). The range was 70–96 (average, 86) for hybrids and 80–95 (average, 87) for lake trout. The substantially lower iodine numbers of the fat of hatchery-reared lake trout than of native lake trout are consistent with findings for wild and hatchery-reared brook trout (Phillips et al., 1957).

TABLE 8.—*Percentage fat and water in the flesh of lake trout from Green Lake, Wisconsin, and a comparison with average fat content of Lake Superior siscowets and lake trout*

| Green Lake, Wisconsin | | | | | Lake Superior[1] | |
|---|---|---|---|---|---|---|
| Date of collection | Total length (inches) | Weight (pounds) | Percentage water | Percentage fat (dry weight) | Percentage fat | |
| | | | | | Siscowet | Lake trout |
| Form A | | | | | | |
| November 1953 | 30.0 | 9.3 | 64.6 | 45.0 | 80.7 | 34.4 |
| November 1953 | 31.0 | 11.7 | 56.0 | 58.7 | 82.0 | 35.7 |
| November 1953 | 31.0 | 12.4 | 52.3 | 60.2 | 82.0 | 35.7 |
| December 1959 | 34.7 | 17.4 | 35.5 | 60.9 | 86.0 | 40.1 |
| November 1953 | 36.0 | 21.4 | 55.8 | 61.7 | 87.6 | 41.6 |
| November 1953 | 36.0 | 21.4 | 37.7 | 67.9 | 87.6 | 41.6 |
| Form B | | | | | | |
| December 1959 | 31.4 | 10.7 | 64.9 | 24.3 | 82.4 | 36.2 |
| November 1953 | 31.5 | 10.2 | 69.8 | 23.3 | 82.6 | 36.3 |

[1] Values for Lake Superior fish are from the curves of Figure 2. (The curve for siscowets was projected to a fish length of 36.0 inches.)

content of the flesh (Table 8). One group of six fish (including one fish from the December 1959 collection), 30.0 to 36.0 inches long (here termed Form A), had a fat content of 45.0 to 67.9 per cent—average, 59.1. The percentage fat increased progressively with increasing length. Fat content of the smallest fish was about 11 percentage points above the mean for Lake Superior lake trout of this length, whereas the other five fish were midway between the average for siscowets and lake trout from Lake Superior. For these five fish, the average deviation was 23 percentage points from both the curve for siscowets and the curve for lake trout (from Figure 2). The average fat content of the flesh of the two Green Lake fish of Form B was 23.8 per cent, or 12.5 percentage points below the average (and outside our range of variation) for Lake Superior lake trout of the same lengths, and about 36 percentage points below two Green Lake fish of Form A of similar length. The iodine number of five of the six fish for which data are available averaged 150 (range, 124–164)—substantially higher than the means for lake trout and siscowets of comparable size from Lake Superior (Table 3).

This small series of flesh samples from lake trout of Green Lake appears to substantiate the presence of subpopulations, which were earlier recognized as different in gross appearance and date of spawning. The findings also demonstrate the occurrence of forms with fat contents midway between those of siscowets and lake trout from Lake Superior.

## ACKNOWLEDGMENTS

Joseph Beil, Leo F. Erkkila, and Russell Robertson assisted in making the field collections. The Michigan Department of Conservation supplied hatchery-reared fish for analysis. Vernon A. Hacker provided specimens from Green Lake, Wisconsin. Richard F. Dumas, Hugh A. Poston, and the late Donald R. Brockway assisted in the analytical work. M. J. DeBoer, Robert R. Miller, Richard L. Pycha, and C. Troy Yoder supplied information. Ralph Hile made suggestions on the manuscript. William Cristanelli prepared the illustrations.

## LITERATURE CITED

AGASSIZ, LOUIS. 1850. Lake Superior: its physical character, vegetation, and animals, compared with those of other and similar regions. Gould, Kendall, and Lincoln, Boston. x + 428 pp.

ASSOCIATION OF OFFICIAL AGRICULTURAL CHEMISTS. 1960. Official methods of analysis of the Association of Official Agricultural Chemists. Washington, D. C. (9th edition; William Horwitz, ed.), 832 pp.

EDDY, SAMUEL, AND THADDEUS SURBER. 1947. Northern fishes with special reference to the Upper Mississippi Valley. Univ. of Minn. Press, Minneapolis. xii + 276 pp. (Revised edition.)

ESCHMEYER, PAUL H. 1955. The reproduction of lake trout in southern Lake Superior. Trans. Amer. Fish. Soc., 84(1954): 47–74.

———. 1957. Note on the subpopulations of lake trout in the Great Lakes. *In* Contributions to the study of subpopulations of fishes. U. S. Fish and Wildl. Serv., Spec. Sci. Rept.—Fish. No. 208: 129.

GOODE, G. BROWN. 1884. The food fishes of the United States. U. S. Comm. of Fish and Fisheries, The Fisheries and Fishery Industries of the United States, Sect. 1: 163–682.

HACKER, VERNON A. 1957. Biology and management of lake trout in Green Lake, Wisconsin. Trans. Amer. Fish. Soc., 86(1956): 71–83.

HUBBS, CARL L., AND KARL F. LAGLER. 1958. Fishes of the Great Lakes region. Cranbrook Inst. Sci., Bull. No. 26, xiii + 213 pp. (Revised edition.)

JORDAN, DAVID STARR, AND BARTON WARREN EVERMANN. 1911. A review of the salmonoid fishes of the Great Lakes with notes on the whitefishes of other regions. Bull. U. S. Bur. Fish., 29(1909): 1–41.

JORDAN, DAVID STARR, AND C. H. GILBERT. 1883. Synopsis of the fishes of North America. Bull. U. S. Natl. Mus., 16: lvi + 1018 p.

MORAWA, F. W. FRITHJOV. 1958. Einige Beobachtungen über die Schwankungen des Fett und Wassergehaltes von Fischer aus verschiedenen Umweltverhältnissen. Int. Assoc. Theoret. and App. Limnology, Helsinki, 13(1956): 770–775.

———. 1960. Jahreszeitliche veränderungen der chemischen und gewichtsmässigen Zusammensetzung von *Coregonus fera* Jurine des Genfer Sees. Ann. Sta. Cent. D'hydrobiologie Appliquée, 8: 283–306.

PHILLIPS, ARTHUR M., JR., DONALD R. BROCKWAY, FLOYD E. LOVELACE, AND HENRY A. PODOLIAC. 1957. A chemical comparison of hatchery and wild brook trout. Prog. Fish-Cult., 19(1): 19–25.

PHILLIPS, ARTHUR M., JR., FLOYD E. LOVELACE, DONALD R. BROCKWAY, AND GEORGE C. BALZER, JR. 1952. The nutrition of trout. Cortland Hatchery Rept. No. 21 for the year 1952. 46 pp.

THURSTON, CLAUDE E. 1962. Physical characteristics and chemical composition of two subspecies of lake trout. J. Fish. Res. Bd. Can., 19(1): 39–44.

WALKER, PERCY H., AND LORIN H. BAILEY. 1914. A simple extraction apparatus. J. Industrial and Engineering Chemistry, 6(6): 497–499.

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# Acid-Fast Staining of Haplosporidian Spores in Relation to Oyster Pathology

by

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# Acid-Fast Staining of Haplosporidian Spores in Relation to Oyster Pathology

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*Accepted September 23, 1964*

Infected tissues from the oyster *Crassostrea virginica* (Gmelin), were subjected to a modified Ziehl-Neelsen carbol fuchsin technique in order to determine whether haplosporidian parasites produced spores with acid-fast properties. *Minchinia costalis* (Wood and Andrews, 1962) Sprague, 1963, sporoplasm was found to be quite acid-fast, remaining bright red after the acid destaining procedure. A combined staining technique employing the Ziehl-Neelsen procedure with Harris' hematoxylin and eosin was devised and applied to oyster samples collected from Pocomoke Sound, Maryland over a 3-year period. Although 235 of these oysters were infected with a haplosporidian-like organism labeled MSX, no spores with acid-fast properties were observed.

## Introduction

The occurrence of mass mortalities of the oyster, *Crassostrea virginica* (Gmelin), along the East Central Coast since 1957 has stimulated intensive research efforts in oyster pathology. A relationship was found between dead and dying oysters and a multinucleate organism thought to be a haplosporidian by a number of East Coast investigators (Engle and Rosenfield, 1962). Efforts to classify this organism, temporarily termed MSX, have been frustrated because a spore stage has not been found. During this time a new oyster disease caused by a haplosporidian, *Minchinia costalis* (Wood and Andrews, 1962) Sprague, 1963, was described from seaside Virginia and Chincoteague Bay. This organism, although having some stages very similar to MSX, produces typical haplosporidian spores. This paper describes attempts to find a stain for haplosporidian spores which would facilitate a quick and efficient method of finding spores of MSX and other haplosporidians if they occur in oyster tissue.

## Materials and Methods

A little-known method for demonstrating acid-fast microsporidian spores with Ziehl's carbol fuchsin (Kudo, 1924) was used with modifications on: (1) *Minchinia costalis* spores in the tissue of a heavily infected oyster from Chincoteague Bay, Virginia; (2) sections from 134 MSX-infected oysters collected over a 2-year period from Marumsco Bar, Pocomoke Sound, Maryland; and (3) 850 random sample oysters from Pocomoke Sound collected periodically from July 1963 to May 1964. Smears, cryostat, and paraffin sections were stained. Smears were fixed with methyl alcohol or Davidson's fixative (Shaw and Battle, 1957). Tissues for sections were fixed in Davidson's fixative. Two staining procedures were used.

### *Procedure I*

1. Remove paraffin with xylene and pas slides through graded alcohols to wate (xylene step was not applicable to cryosta sections and smears).

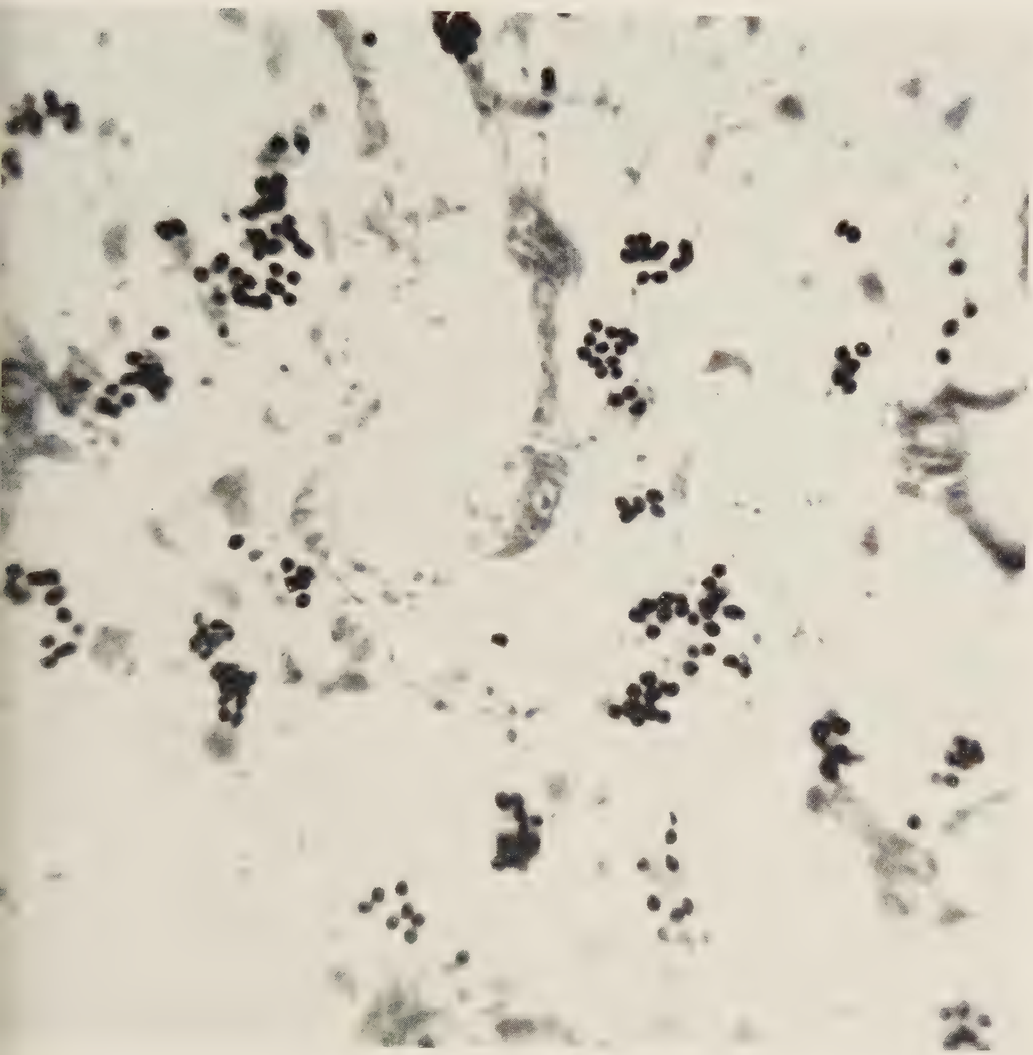

FIG. 1. Ziehl's fuchsin stained, acid destained, cryostat section of oyster heavily infected with *Minchinia* *stalis*. Darkly stained bodies are mature spores. 900 ×.

2. Stain preparations 15 minutes in Ziehl's chsin prepared with basic fuchsin (Certifica- on No. 69, C. I. 42500, Allied Chemical Co.) outlined in Gray (1954:316).

3. Destain in 0.1 *N* $H_2SO_4$ by microscopic amination until tissues destain, leaving acid- st sporoplasms bright red (15 to 30 sec- ds).

4. Wash in tap water 10 minutes.

5. Dehydrate through graded alcohols; ear in xylene and mount with permount.

*Procedure II*

1. After Step 4. of Procedure I, stain preparations 2 minutes in Harris' hematoxylin (Lot #730162—Fisher Scientific Co.).

2. Wash in tap water 1 minute.

3. Differentiate in saturated aqueous $Li_2CO_3$ for 2 minutes.

4. Pass through graded alcohols, to 95% alcohol.

5. Counterstain in saturated solution of

eosin bluish alcohol soluble (Cat. #525, Allied Chemical Corp.) in 95% alcohol.

6. Dehydrate further in two changes of 100% alcohol, clear in xylene and mount in permount.

## RESULTS

Staining Procedure I was used first on known *Minchinia* spores, resulting in a very specific staining reaction. After treatment with the acid solution, all mature spores were found to contain bright red sporoplasm, while spore walls and host tissue failed to retain any of the stain. Immature spores showed partially stained sporoplasm. Subsequent use of this technique on tissues of 134 MSX-infected oysters failed to demonstrate acid-fast sporoplasm. An acid-fast substance was found to occur occasionally in the gonadal region of some oysters during gametogenesis.

Procedure II was applied to the *M. costalis*-infected tissue in an attempt to incorporate sporoplasm staining with the standard Harris' hematoxylin-eosin technique already in use as a diagnostic procedure for oyster parasites. As expected, sporoplasm retained its acid-fast properties, while oyster tissues and pre-spore stages of the parasite were stained normally with the hematoxylin and eosin stains.

The combined staining technique was incorporated into the routine histologic procedure used for oyster pathology studies of Marumsco Bar samples. Although 101 of the 850 oysters collected over a 10-month period were found to be infected with MSX, no spores with acid-fast sporoplasm were observed. Several types of acid-fast bodies were seen in the gut lumens of feeding oysters. Among these were a variety of unidentified spores. Spores of *Nematopsis ostearum* (Prytherch) (a gregarine parasite of oysters commonly found in these slides) were not acid-fast, the wall and sporoplasm staining basophilically with hematoxylin.

## DISCUSSION

The Ziehl-Neelsen carbol fuchsin technique for acid-fastness has been used extensively in the past to demonstrate acid-fast bacteria notably *Mycobacterium*. The reasons for acid-fastness are not fully understood, but severa theories have been suggested. Knaysi (1929 thought that acid-fastness in bacteria was du to a waxy sheath. Mycolic acid, an acid-fas substance isolated from tubercle bacilli b Anderson (1932), was suggested as an explanation of the reaction; but this substanc has only a light pink color when stained in film comparable in thickness to the tubercl bacillus, which stains brilliant red (Smith an Martin, 1948). Pearse (1960) discussed th acid-fast properties of lipofuscin, an anima pigment oxidized from lipids. From his discussion it appears that autoxidizing lipoids become acid-fast and continue oxidizing to for ceroid type and other forms of lipofuscins Vertebrate ceroid is PAS positive and mor oxidized forms exhibit strong basophilia. *M costalis* spores were found to be PAS negativ and nonbasophilic. Therefore, if the substanc which causes acid-fastness in the sporoplasm is in the lipid group it is probably an autoxidizing lipoid. The specific staining of only th sporoplasm helps dispel the waxy sheat theory for *Minchinia* spores.

From my own observations it appears tha the acid-fastness of the *Minchinia* sporoplasm is either due to the stain being retained withi the sporoplasmic membrane or by a chemica bond between the stain and some substanc (perhaps an oxidized lipoid) in the sporoplasm. The latter statement is most probabl true, for the former implies that the sporoplasmic membrane is impervious to acid an pervious to the stain.

The demonstration of acid-fastness in haplosporidian spore may prove to be usefu in several ways: (1) in a practical way—as quick and efficient method of locating haplosporidian spores in tissues; and (2) in a theoretical way—it may prove to be a valuab tool in histochemical sporozoan systematics.

The absence of acid-fast spores in MSX infected tissues indicates one or more of th following:

1. MSX has no acid-fast spore stage. This could place the organism in another taxon.
2. The spore may develop in an alternate host.
3. Environmental conditions may not favor spore development.
4. The oyster may be an unnatural or facultative host which hinders development of the parasite life cycle.

Similar staining experiments with spores of other species of Haplosporidia are needed to answer many of the questions raised.

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I should like to express my appreciation to Dr. Victor Sprague and Dr. John L. Wood for critical review of the manuscript.

### REFERENCES

ANDERSON, R. J. 1932. The chemistry of the lipoids of tubercle bacilli. *Phys. Rev.*, **12**, 166-189.

ENGLE, J. B., AND ROSENFIELD, A. 1962. Progress in oyster mortality studies. *Proc. Gulf and Caribbean Fish. Inst.*, pp 116-124.

GRAY, P. 1954. "The Microtomist's Formulary and Guide," 794 pp. Blakiston, New York and Toronto. See p. 316: 11.431.

KNAYSI, G. 1929. The cytology and microchemistry of *Mycobacterium tuberculosis. J. Infect. Dis.*, **45**, 13. 13-33.

KUDO, R. 1924. A biological and taxonomic study of the Microsporidia. *Ill. Biol. Monogr.*, **9**, 1-268.

PEARSE, A. G. E. 1960. "Histochemistry: Theoretical and Applied," 2nd ed., 998 pp. Little, Brown, Boston, Massachusetts.

SHAW, B. L., AND BATTLE, H. I. 1957. The gross and microscopic anatomy of the digestive tract of the oyster *Crassostrea virginica* (Gmelin). *Can. J. Zool.*, **35**, 325-347.

SMITH, D. T., AND MARTIN, D. S. 1948. "Zinsser's Textbook of Bacteriology," 9th ed., 992 pp. Appleton-Century-Crofts, New York.

SPRAGUE, V. 1963. Revision of Genus *Haplosporidium* and restoration of Genus *Minchinia* (Haplosporidia, Haplosporidiidae). *J. Protozoöl.*, **10**, 263-266.

WOOD, J. L. AND ANDREWS, J. D. 1962. *Haplosporidium costale* (Sporozoa) associated with a disease of Virginia oysters. *Science,* **136**, 710-711.

# A MODIFICATION OF NOLAND'S STAIN FOR PERMANENT SMEARS OF PROTOZOAN FLAGELLA, CILIA, AND SPORE FILAMENTS

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# A Modification of Noland's Stain for Permanent Smears of Protozoan Flagella, Cilia, and Spore Filaments

Identification of flagellates and ciliates often requires counting flagella and ciliary rows and observing their origin. One of the criteria for classifying microsporidians and myxosporidians is the presence and number of spore filaments. Noland's temporary wet mount technique (Noland, Science **67:** 535, 1928), while an excellent method for flagella staining, has two disadvantages:

1. it causes some organisms such as *Paramecium* sp. and the oyster flagellate, *Hexamita* sp., to expel their cilia or flagella, and
2. preparations are temporary and cannot be saved for future study and documentation.

A quick, easy method for making permanent smears of organisms which demonstrate flagella, cilia, and spore filaments has been developed for use in oyster pathology; however, the technique could be applied to any organism possessing these structures.

The modified staining technique was applied to *Hexamita* sp., a facultative oyster parasite (Fig. 1); *Ancistrocoma pelseneeri* (Chatton and Lwoff), a ciliate gut parasite of the eastern oyster, *Crassostrea virginica* (Gmelin); and a microsporidian parasite, *Nosema* sp. (Sprague, J. Prot. **12:** 66–70, 1965) of the Chesapeake Bay blue crab, *Callinectes sapidus* (Rathbun).

The procedure is as follows:

(1) Make thin film smears of flagellates, ciliates, or sporozoan spores from fresh material. If spore filaments are to be stained they must be extruded first, under a cover slip, by applying pressure. The cover slip is removed before the next step.

(2) Air dry the smears for 1 hr.

(3) Stain smears 2 to 3 min with Noland's stain, prepared by moistening 20 mg gentian violet with 1 ml water, then adding 80 ml saturated aqueous phenol, 40 ml 40% formaldehyde, and 4 ml glycerol.

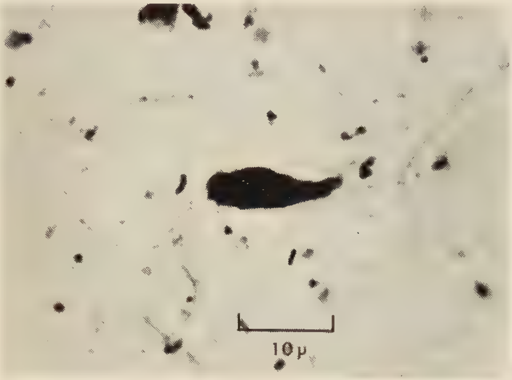

FIGURE 1. *Hexamita* sp. A flagellate from the oyster *Crassostrea virginica* showing the eight flagella and their approximate origin. Noland's stain 970 ×.

(4) Immediately place the slide in running tap water, and wash for 3 min. If the stain is allowed to dry before the rinse, a precipitate is formed which interferes with examination.

(5) Blot smears between bibulous paper and allow them to air dry completely (1 to 2 hr or longer).

(6) Place one drop of Permount on smear and cover with xylene-moistened cover slip to facilitate easy spreading of the mounting medium.

All organic material, including flagella and spore filaments, stains deep blue. Smears which demonstrate flagella or filaments have been kept more than a year without deterioration.

I would like to thank Dr. Victor Sprague for supplying fresh microsporidian spore material.

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# PATHOLOGIC RESPONSES OF THE OYSTER, *CRASSOSTREA VIRGINICA* (GMELIN), TO INFECTION BY THE PROTISTAN PARASITE, MSX

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# PATHOLOGIC RESPONSES OF THE OYSTER, *CRASSOSTREA VIRGINICA* (GMELIN), TO INFECTION BY THE PROTISTAN PARASITE, MSX.

C. Austin Farley, Bureau of Commercial Fisheries Biological Laboratory, Oxford, Maryland.

**(Abstract)**

**A multinucleate, haplosporidian-like parasite, designated MSX, has occurred in the tissues of oysters collected from Delaware and Chesapeake Bays during recent periods of heavy mortality. Critical examination was made of live oysters and histological sections of oyster tissues from random samples collected from Marumsco Bar, Pocomoke Sound, Md., to study the pathologic relationship between host and parasite. Infections have been classified into five pathologic categories related to the sequence of infection.**

**(1) *Initial infections*, found most commonly in July, August, and early September, are characterized by localized infection in the gills of oysters. Intracellular plasmodia are seen first in the columnar epithelial cells; a clear area, thought to be lysis, usually surrounds them. Plasmodia then migrate to the basement membrane where plasmotomy occurs, and thence into the connective tissue and blood sinuses of the gill. Host response, recognized by a massive concentration of small (8$\mu$) lymphocyte-like cells with large (5$\mu$) nuclei, is evident in affected areas.**

(2) *Intermediate infection* follows initial infection or occurs as the result of relapse of chronic infection. It is characterized by localized lesions, with accompanying host response in the gill, gonad, diverticulae, and connective tissue adjacent to gut and mantle epithelia. Recessive shell growth and shell-pustule formation may occur in this phase. *Intermediate infections* resulting from *initial infections* can be differentiated from *relapsed intermediate infections* by the occurrence of lesions in the gill, gonad, and epithelium of the gut; *relapses* are usually characterized by localized lesions in the diverticulae and connective tissue adjacent to gut and mantle epithelium. *Relapses* were most common in June. *Intermediate infections*, which follow closely and overlap initial infections, were most frequent in July, August, and September.

(3) *Advanced infection* was most prevalent from September through December. It is characterized by massive infection and host response throughout the oyster, resorption of gametes, shrinkage of gonad tubules, and a marked tendency toward recessive shell growth.

(4) *Terminal infections* exhibit massive invasion of tissues but the intensity of infection may vary, depending on the length of time the infection is carried before death occurs. Host response is usually light or absent and pycnosis of host and parasite cells is often apparent. *Terminal infections* are evident before and during mortality periods in the fall and winter. Recessive shell growth is usually present.

(5) *Recovery* is thought to occur in some oysters and is recognized by the deposition of yellow–brown, conchiolin-covered shell pustules, which is preceded by the formation of localized fibrocytic lesions in the tissue near and in mantle epithelium. Moribund MSX can be found in both lesions and shell pustules, but rarely elsewhere in the tissue. This syndrome occurs most commonly in the summer and fall. Another phase which occurs in the winter and spring is characterized by a marked decrease of infection intensity in *advanced infections*; recognizable MSX occurs most commonly near and in epithelia. Many oysters collected during this time, which exhibit no diagnosable infection, have recessive growth, and it is thought that these represent chronic infections which relapse into the active intermediate infections as described above.

# First Transponding Oceanographic Buoys in the Pacific[1]

By F. Favorite, D. Fisk, and W.J. Ingraham, Jr.

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## ABSTRACT

Three transponding oceanographic buoys were released off the Washington coast during May 1964. One drifted over 320 miles 155° T at a speed of almost 5 miles per day. Two buoys, 1000 yards apart on May 29, were recovered 58 miles apart on July 17. Attempts to track the buoys at 10-day intervals by aircraft were unsuccessful. Communications using a frequency of 2690 kc were unsatisfactory at ranges in excess of 200 miles, but an interrogation and transponding range of 900 miles was obtained using 4134.5 kc.

## INTRODUCTION

Fishery research at this Laboratory has undergone significant changes in the last decade. Prior to 1953, priority was given to research associated with management problems in the Columbia River and Alaskan streams; a marine program was virtually nonexistent. From 1953 to the present time, a large part of the Laboratory's research has been directed toward answering problems confronting the United States Section of the International North Pacific Fisheries Commission. Most of these studies have been of a marine nature and have been carried out in the north-central North Pacific Ocean and Bering Sea (Dodimead *et al.*, 1963). Increased fishing activity of foreign vessels in the Gulf of Alaska has made it mandatory for us to know as much as possible about local fish stocks and the oceanographic conditions that affect their abundance and distribution, if they are to be protected by international agreements.

Movement of surface water off the west coast of the United States is very complex and not too well known. Drift bottle studies off the southern California coast indicate a northward flow of water along Oregon and Washington during winter (Reid, 1959), and there is good evidence of a southward flow during spring and summer (Budinger *et al.*, 1964). However, the predominant surface movement of oceanic water as indicated by drift bottles (Favorite, 1964) is onshore (Fig. 1). This condition is rather unique along the United States coastline and makes our area ideally suited for investigations using drifting buoys.

The purpose of our first experiment was threefold: to test the seaworthiness of radio buoys in the rough seas common to northern Pacific waters; to ascertain the range of transmission and reliability of the radio equipment; and to determine the feasibility of locating the buoys by ship and aircraft.

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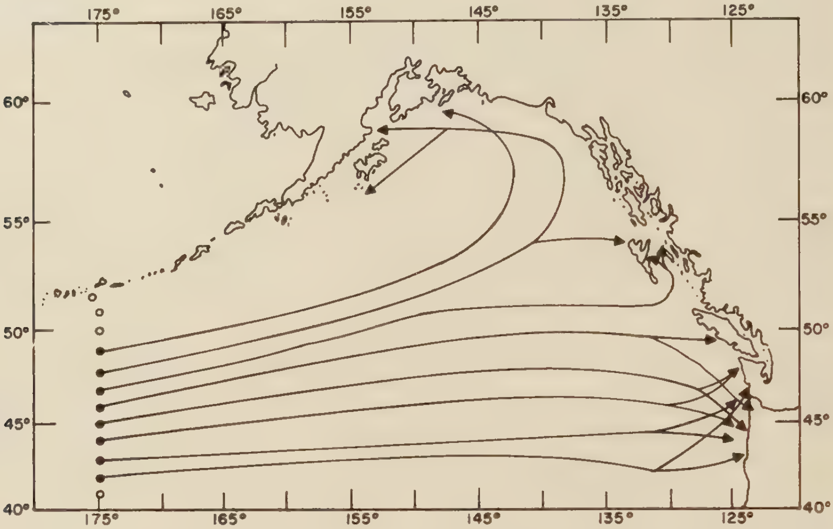

FIG. 1. Locations of release and recovery of drift bottles, 1962–64 (open circles indicate no recoveries).

## DESCRIPTION OF BUOY

In order that our investigations be of maximum use to fishing interests, we felt that the information obtained should be instantly available and reflect existing rather than average conditions. Thus, we decided to use radio buoys that would measure oceanographic conditions and transmit data directly to our Seattle Laboratory. Use of batteries required that the buoys be transponding, transmit only when interrogated, so that power would be expended only when information was requested.

The buoy selected was manufactured by Concord Control, Inc., of Boston, Massachusetts. The case, 14 ft long and 8 inches in diameter, is constructed of aluminum tubing protected by a plastic coating and contains the battery and electronics assembly (Fig. 2). The lower end is closed by a damping plate and provides a RF sea ground, and a 13-ft antenna is attached to the top. A cylindrical plastic chamber, 3½ ft in diameter and 3½ ft high, filled with polyurethane foam, surrounds the top of the case providing stability and buoyancy, as well as providing protection for small craft. Large, alternating, horizontal fluorescent red and yellow bands permit identification of the buoy at distances of several miles. Each buoy, upon interrogation by a sequential two-tone radio signal, responds by transmitting its individual call sign and whatever intelligence is programmed into the electronics assembly (Morin and Walden, 1963).

## RESULTS

Reconnaissance flights were conducted by U.S. Coast Guard aircraft from Port Angeles Air Station, and the buoys were released and recovered by the Bureau of Commercial Fisheries research vessel *George B. Kelez*. Several re-

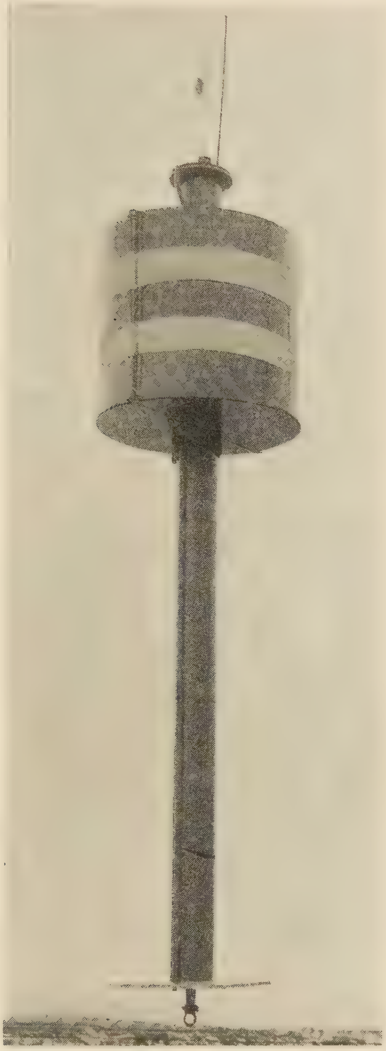

FIG. 2. Telemetry buoy being hoisted aboard the RV *George B. Kelez* (13-ft whip antenna not visible).

strictions were imposed by available equipment and operating schedules. Although a frequency of 4134.5 kc had been selected for this experiment on the basis of considerations of maximum range of transmission with minimum of power loss, maximum bearing accuracy, and frequencies available for oceanographic use, the aircraft direction finding (DF) equipment was limited to only low or very high frequencies. The only frequency available that was compatible with both plane and buoy equipment was the Coast Guard frequency, 2690 kc, and we were given permission to use it during May, June, and July. Further, during the early phase of the experiment only one tone generator was available to interrogate the buoys and it was installed aboard the *Kelez*. Finally, the initial release location and the number of buoys released were chosen with the realization that for this experiment the operating range of the aircraft was 300 miles, and that the services of the *Kelez* would not be available during June.

Our first experiment was conducted with two buoys tuned to 2690 kc. After initial tests with an aircraft in the Strait of Juan de Fuca on May 11, 1964, we released buoy KG7701 approximately 300 miles offshore at 47°30′N lat, 132°00′W long, and buoy KG7707 30 miles north at 48°00′N lat, 132°00′W long (Fig. 3). We had hoped that frequent positioning of the buoys would permit determining the nature of rotary currents known to be present offshore. During the morning of May 13, the buoys were interrogated by the *Kelez* and easily located by a Coast Guard aircraft following the DF bearing of the transponding signals. A maximum range of detection of about 200 miles, considerably less than we had estimated, and a bearing drift to the left as the buoys were approached, were reported.

During this phase of the experiment, we were not able to detect the buoy transmissions at the Bureau of Commercial Fisheries Exploratory Fishing Base radio station KAB, in Seattle. We believed, however, that when the *Kelez* returned to port and the tone generator was installed at KAB, sufficient power, 150 w, would be available to interrogate the buoys, and the 200-mile range of detection of the transponding signal from the buoys by aircraft would insure successful tracking. This was not the case. On May 20, during a flight over the estimated position of the buoys, no transmission from either buoy was detected following interrogations from KAB. On May 29, while the *Kelez* was en route to the Aleutians on another assignment, no difficulty was experienced in locating buoy KG7707 from DF bearings of its transmission in

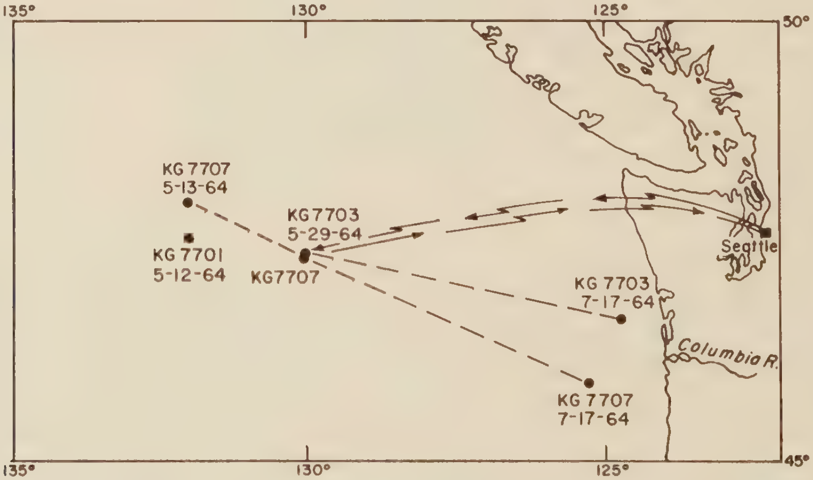

FIG. 3. Locations and dates of release and recovery of telemetry buoys, May–July 1964.

response to shipboard interrogations. It was found at 47°21′N lat, 130°00′W long, and had drifted approximately 90 miles 115° T. Visual inspection, without removing the buoy from the water, indicated that it was in excellent condition. At this time, we had tone generators aboard the *Kelez* and at KAB, and were able to determine that interrogations from KAB were received and responded to only at night. We decided to test communications using our assigned frequency, and on the same day, buoy KG7703, tuned to 4134.5 kc, was released $\frac{1}{2}$ mile away from buoy KG7707. Communications were excellent and we were able to interrogate and receive the transponding transmission during day or night from KAB. No contact was made with buoy KG7701 and its fate is not known at this time. After a thorough search, the *Kelez* continued on to the Aleutians and maintained communication with buoy KG7703 for a distance of over 900 miles.

Through KAB, we were able to maintain communication with buoy KG7703 during June and July. Several other attempts were made to position the buoys from aircraft, but they were unsuccessful even though on one flight the tone generator was mounted in the aircraft.

Buoy KG7707 was recovered by the *Kelez* on July 17, 1964, at 45°54′N lat, 125°18′W long, after drifting over 320 miles at a speed of almost 5 miles per day. The three known positions of the buoy lie on a straight line, 115° T. Buoy KG7703 was recovered the same day at 46°42′N lat, 124°46′W long, approximately 58 miles away. Both were in excellent condition throughout.

## CONCLUSIONS

We consider the experiment to have been a success and will continue to utilize radio buoys in our studies of oceanographic conditions off the Washington coast. We hope to add temperature sensors to the buoys and to seek ways for providing an aircraft DF capability at 4134.5 kc so that the actual paths of the buoys can be ascertained.

Although only three positions of buoy KG7707 are known, a general onshore movement is indicated. Results of a drift bottle study conducted during this period (Fig. 4) suggest that at the time of recovery the buoy had entered the coastal regime, in which the flow was southward.

Today, networks of moored oceanographic buoys have been proposed for recording meteorological and oceanographic data in the North Pacific Ocean. Because such networks will provide insight into fundamental questions of air–sea interactions basic to the production of weather across the United States, it is likely that these networks will become realities in the near future. Optimum use of data from these moored buoys in predicting favorable or unfavorable environmental condition for local fisheries will depend upon careful selection of buoy sites and knowledge of factors influencing movements of fish. As a part of the Bureau of Commercial Fisheries long-range plan, TRIDENT, our research will seek answers to these problems.

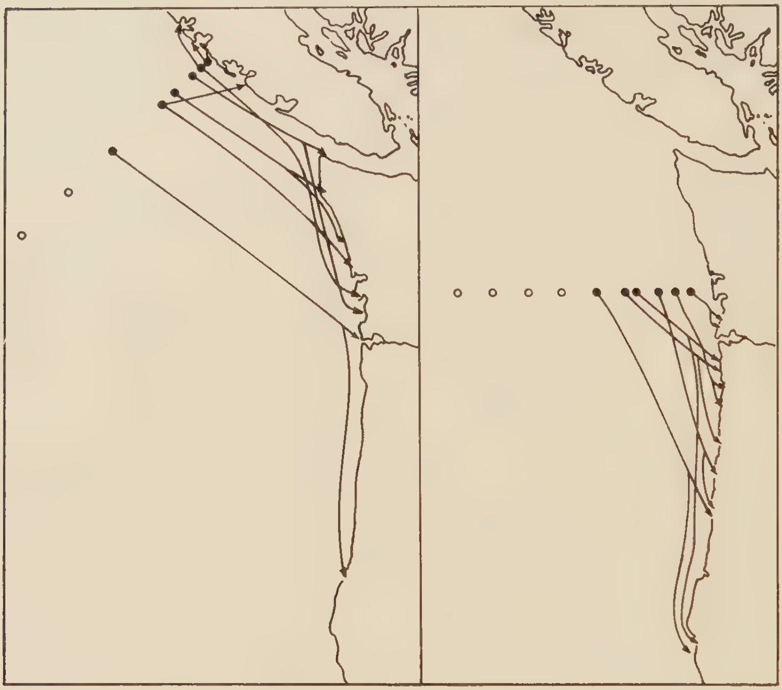

FIG. 4. Locations of release and recovery of drift bottles May–July 1964 (open circles indicate no recoveries).

ACKNOWLEDGMENTS

We wish to thank Commander Warren C. Mitchell, Commanding Officer of the U.S. Coast Guard Air Station, Port Angeles, Washington, and the Captain and crew of the RV *George B. Kelez* for their willing and capable assistance.

## REFERENCES

BUDINGER, THOMAS F., LAWRENCE K. COACHMAN, AND CLIFFORD A. BARNES. 1964. Columbia River effluent in the northeast Pacific Ocean, 1961, 1962: selected aspects of physical oceanography. *Univ. Washington Dept. Ocean. Tech. Rept.*, No. 99, 78 p.

DODIMEAD, A. J., F. FAVORITE, AND T. HIRANO. 1963. Salmon of the North Pacific Ocean, Part II. Review of oceanography of the Subarctic Pacific Region. *Int. N. Pac. Fish. Comm. Bull.*, No. 13, 195 p.

FAVORITE, F. 1964. Drift bottle experiment in the northern North Pacific Ocean. *J. Ocean. Soc. Japan*, **20**(4): 160–167.

MORIN, JOHN O., AND ROBERT G. WALDEN. 1963. Radio telemetering buoys. *Undersea Technology*, **4**(8): 15–17.

REID, JOSEPH L., JR. 1959. Oceanography of the northeastern Pacific Ocean during the last ten years. *Rep. Calif. Coop. Ocean. Fish. Invest.*, **7**: 77–90.

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# THREADFIN SHAD IN TAMPA BAY, FLORIDA

JOHN H. FINUCANE

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# THREADFIN SHAD IN TAMPA BAY, FLORIDA

John H. Finucane

The threadfin shad, *Dorosoma petenense* (Günther), has in recent years become widely introduced as a forage species in fresh-water ponds, lakes, rivers, and reservoirs. It is distributed naturally throughout Florida and in brackish waters of the eastern Gulf coastal region (Carr and Goin, 1955). Little published information is available on its ecology in the estuarine waters of Florida, and its occurrence in Tampa Bay has not previously been reported.

On March 11, 1963, and March 24 and 25, 1965, threadfin shad were collected in Old Tampa Bay at the base of Alligator Lake dam. The lake is a fresh-water impoundment of approximately 85 acres, located just south of Safety Harbor, on the northwest side of Old Tampa Bay. A total of 79 fish were caught by dip net and 2 with a 70-foot beach seine. Standard length (SL) of males ranged in length from 114 to 162 mm (average, 136), and females from 121 to 179 mm (average, 155). Most of the females were gravid. The unfertilized eggs were light yellow, semiadhesive, and ranged from 0.68 to 0.75 mm in diameter. All males had enlarged testes, and the milt was of low viscosity. The number of eggs in a fish 126 mm long totaled 6,210 and in a fish 169 mm long, 21,007.

The shoreline, bottom sediments, and rocks at the base of the dam showed no evidence of recently spawned eggs. Threadfin shad are reported to spawn in areas of heavy aquatic vegetation; eggs have been noted on the roots of water hyacinths, submerged algae, and pilings (Berry, Huish, and Moody, 1956; McLane, 1955).

Several hundred of these fish were observed during high tide on March 25, 1965, at the base of the dam. Threadfin shad are apparently attracted by water currents at the downstream faces of dams and similar obstructions during the spring and fall (Miller, 1963; Parsons and Kimsey, 1954). Water temperature was 22.8 C (63.0 F), and salinity was 8.73 o/oo. No fish were seen during low tide, when the water depth at the base of the dam was less than 3 feet.

Most of the stomachs were nearly empty, although some diatoms (*Chaetoceros* spp.), sand, and unidentifiable organic detritus were noted. The species is reported to feed mainly on plankton (diatoms, copepods, and cladocerans) when in fresh water. Haskell (1959) suggested that threadfin shad are both planktonic and bottom feeders. In the Salton Sea, California, threadfin shad feed on the fry of *Bairdiella icistius* (Miller, 1963).

Mortality of threadfin shad from reduced water temperature has been reported by some investigators. Hubbs (1951) assumed that the minimum temperature tolerance for *Signalosa* (= *Dorosoma*) *petenensis atchafalayae* in the Colorado River was between 12.2 and 14.2 C (54 and 57.6 F), although experiments by Parsons and Kimsey (1954) showed some survival of this fish below 45 F (7.2 C). No mortality of threadfin shad was observed during a winter kill at the sampling site in Old Tampa Bay and other areas in Tampa Bay on December 13-14, 1962, when water temperature reached a record low of 9.6 C or 49.3 F (Rinckey and Saloman, 1964). These data indicate that the normal seasonal temperature range (10 to 35 C — 50.0 to 95.0 F) in Old Tampa Bay probably does not limit threadfin shad.

The average size of the adult fish taken in this study was above that reported from fresh-water lakes in Florida (Berry et al., 1956). The largest female from Old Tampa Bay measured 179 mm SL; this size may indicate that larger fish prefer brackish water. Miller (1963) stated that fish smaller than 100 mm were usually taken in salinities of less than 15 o/oo, and those from 100 to 150 mm occurred more frequently in salinities of 15 to 30 o/oo. The salinity range in Old Tampa Bay is generally between 15 and 25 o/oo (Saloman, Finucane, and Kelly, 1964).

Scales indicated that the fish were in age-group I, between 1 and 2 years old. Generally, this species has a short life, for few individuals seem to live longer than 2 years (Miller, 1963; Parsons and Kimsey, 1954). The brief life span may be the result of spawning mortality, as noted by Berry et al. (1956), who observed two mass mortalities of threadfin shad in Florida lakes that were attributed to spawning.

The origin of this species in Old Tampa Bay is unknown. According to local residents, threadfin shad were stocked in Alligator Lake as forage food for largemouth bass, *Micropterus salmoides floridanus*. The dam has been washed out several times since 1959; each time the lake was partially or completely drained. Possibly threadfin shad were released into Old Tampa Bay during the wash-outs. Springer and Woodburn (1960) reported *D. petenense* from Lake Maggiore (in St. Petersburg), which has an outlet into lower Tampa Bay. Either of these two lake populations could have been responsible for the presence of the species in Tampa Bay.

To judge from the numbers of threadfin shad seen in 1965, the species has become firmly established in Old Tampa Bay. In California, transplants of threadfin shad in the Colorado River during 1954 resulted in a population eruption at the end of 1955 in every habitable part of the Colorado River drainage system (Kimsey, 1957; Shapovalov, Dill, and Cordone, 1959). If threadfin shad become plentiful in Old Tampa Bay, they may be kept under control by such predators as snook, *Centropomus undecimalis,* sand seatrout, *Cynoscion arenarius,* spotted seatrout, *C. nebulosus,* and silver perch, *Bairdiella chrysura.* Additional ecological studies are needed to determine fully the effects of the threadfin shad on the resident biota.

## ACKNOWLEDGMENTS

Messrs. Arthur R. Marshall, Bureau of Sport Fisheries and Wildlife, Branch of River Basins Studies, and John L. Taylor of our staff collected some threadfin shad for this study.

## LITERATURE CITED

BERRY, FREDERICK H., M. T. HUISH, AND H. MOODY. 1956. Spawning mortality of threadfin shad, *Dorosoma petenense* (Günther), in Florida. Copeia, no. 3, p. 192.

CARR, ARCHIE, AND COLEMAN J. GOIN. 1955. Guide to the reptiles, amphibians and fresh-water fishes of Florida. University of Florida Press, Gainesville, pp. 1-341.

GUNTER, GORDON. 1945. Studies on marine fishes of Texas. Publ. Inst. Mar. Sci., vol. 1, no. 1, pp. 1-190.

HASKELL, WILLIAM L. 1959. Diet of Mississippi threadfin shad, *Dorosoma Petenense atchafalayae,* in Arizona. Copeia, no. 4, pp. 298-302.

HUBBS, CLARK. 1951. Minimum temperature tolerances for fishes of the genera *Signalosa* and *Herichthys* in Texas. Copeia, no. 4, p. 297.

KIMSEY, J. B. 1958. Fisheries problems in impounded waters of California and the lower Colorado River. Trans. Amer. Fish Soc., vol. 87 (1957), pp. 319-362.

MCLANE, WILLIAM. 1955. Fishes of the St. Johns River system. University of Florida (unpublished thesis).

MILLER, ROBERT RUSH. 1963. Fishes of the western north Atlantic. (Part III) Sears Found. for Mar. Res., Yale University, pp. 443-451.

PARSONS, JOHN W., AND J. BRUCE KIMSEY. 1954. A report on the Mississippi threadfin shad. Prog. Fish Cult., vol. 16, no. 4, pp. 179-181.

RINCKEY, GORDON R., AND CARL H. SALOMAN. 1964. Effect of reduced water temperature on fishes of Tampa Bay, Florida. Quart. Jour. Florida Acad. Sci., vol. 27, no. 1, pp. 9-16.

SALOMAN, CARL H., JOHN H. FINUCANE, AND JOHN A. KELLY, JR. 1964. Hydrographic observations of Tampa Bay, Florida, and adjacent waters, August 1961 through December 1962. U. S. Fish Wildl. Serv., Data Rep. 4 microfiche.

SHAPOVALOV, LEO, W. A. DILL, AND A. J. CORDONE. 1959. Revised checklist of fresh-water and anadromous fishes of California. Calif. Fish. and Game, vol. 75, no. 3, pp. 159-177.

SPRINGER, VICTOR G., AND KENNETH D. WOODBURN. 1960. An ecological study of the fishes of the Tampa Bay area. Florida State Board Conserv., Prof. Pap. Ser., no. 1, pp. 1-104.

*Bureau of Commercial Fisheries Biological Station, St. Petersburg Beach, Florida.* Contribution No. 19.

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# The Use of Catch–Effort, Catch–Sampling, and Tagging Data to Estimate a Population of Blue Crabs[1]

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## ABSTRACT

Catch–effort, and catch–sampling data along with the results of a tagging study are used to estimate the size of the blue crab, *Callinectes sapidus,* population in the Neuse River, North Carolina, during 1958. At the beginning of July, estimates of the crab population, determined by three methods, were 716,000, 703,000, and 722,000 pounds, respectively. Catch, recruitment, and emigration of mature female crabs from the river affected abundance, whereas natural mortality and predation upon crabs were considered insignificant. Of the 2.1 million pounds of crabs estimated as being available to the fishery during 1958, 1.7 million pounds were caught.

## INTRODUCTION

During the past 50 years, and especially in the past two decades, large and sudden declines in abundance of the blue crab, *Callinectes sapidus,* along the Atlantic coast of the United States have adversely affected the crab industry. As a result, the crab industry, through the Atlantic States Marine Fisheries Commission, asked the U. S. Fish and Wildlife Service to undertake a research program to determine causes of fluctuations, and to recommend measures for obtaining optimum continuing yields from the resource. One phase of this program was the estimation of crab abundance so that effects of factors affecting abundance could be assessed.

The U. S. Fish and Wildlife Service began work on blue crabs in 1957, and in 1958 the commercial fishery for blue crab in the Neuse River, North Carolina, was studied. The purpose of the study was to develop methods of estimating abundance that would apply to the population in this river and would aid in understanding the dynamics of crab populations in other areas. This paper presents three methods used to estimate the size of the crab population in the Neuse River from the spring to the fall of 1958.

## LIFE HISTORY OF THE BLUE CRAB

Sexual maturity of crabs in Chesapeake Bay is reached in about 1½ years and after approximately 27 molts following hatching (Van Engel, 1958; Costlow and Bookhout, 1959). In the Neuse River the number of molts until sexual maturity is believed to be the same, but the period of time for these molts is shorter.

Young crabs move into the Neuse River from Pamlico Sound (Figure 1). Growth, which occurs at molting, takes place from spring to fall. Before a crab molts, a new skin or shell is formed beneath the hard outer shell. A crab approaching the time of shedding is called a "peeler" crab. After the hard shell is shed, the new, soft, pliable outer covering expands and begins to harden. Within approximately 24 hours the shell has hardened so that a crab cannot be marketed as a "soft" crab.

After their last molt, and while still soft, female crabs mate and then move from the river into the more saline waters of Pamlico

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[1] Part of a Master's thesis submitted to the College of Fisheries, University of Washington, Seattle, Washington.

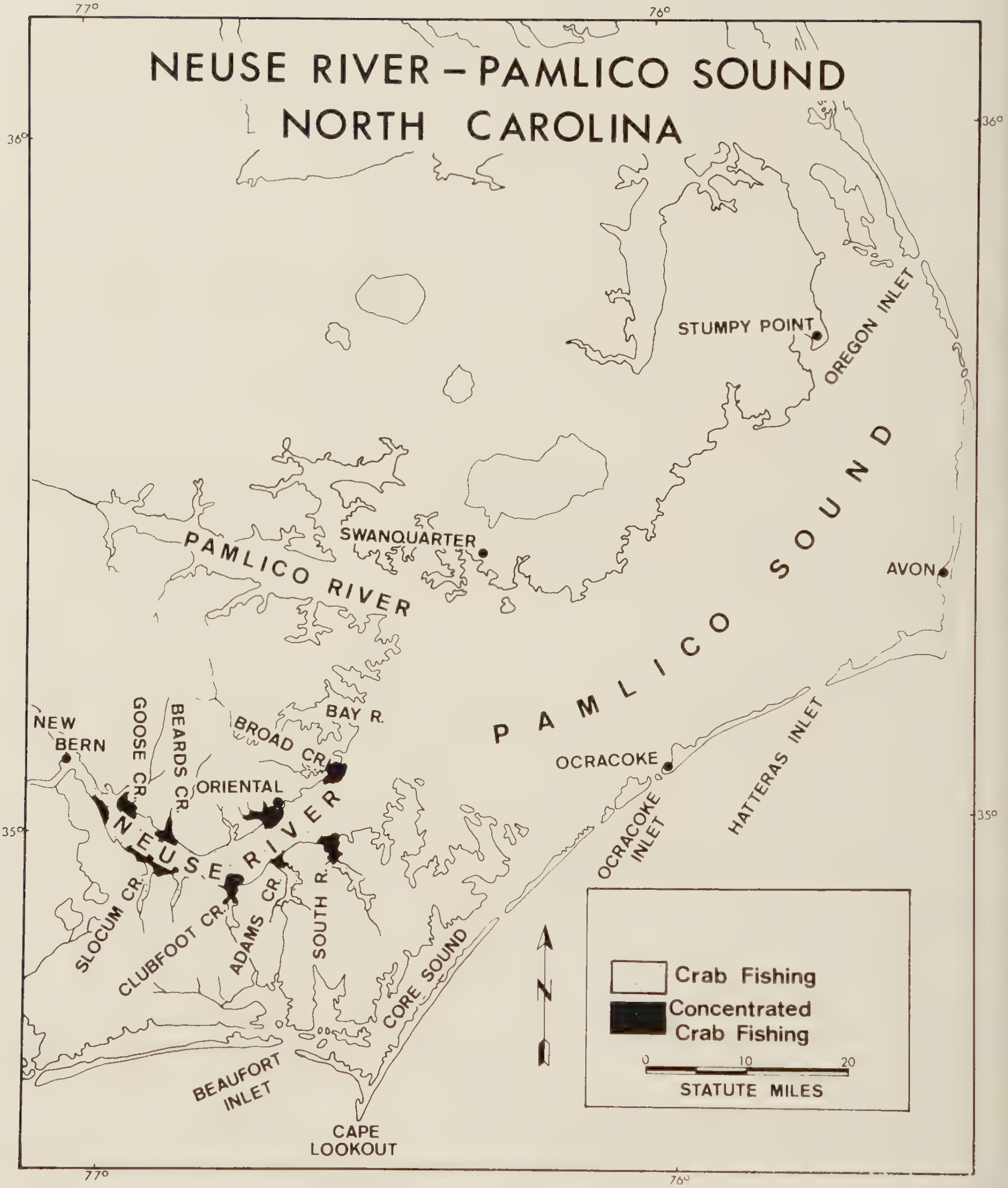
NEUSE RIVER – PAMLICO SOUND
NORTH CAROLINA
77°
76°
36°
35°
STUMPY POINT
OREGON INLET
SWANQUARTER
PAMLICO RIVER
PAMLICO SOUND
AVON
NEW BERN
GOOSE CR.
BEARDS CR.
BAY R.
BROAD CR.
ORIENTAL
NEUSE RIVER
OCRACOKE
HATTERAS INLET
OCRACOKE INLET
SLOCUM CR.
CLUBFOOT CR.
ADAMS CR.
SOUTH R.
CORE SOUND
N
Crab Fishing
Concentrated Crab Fishing
0 10 20
STATUTE MILES
BEAUFORT INLET
CAPE LOOKOUT

FIGURE 1.—Neuse River–Pamlico Sound, North Carolina.

and Core Sounds. Mating, and the movement of the females, occurs mainly from May to October. The males remain in the river until fall. Spawning females produce large numbers of eggs which become attached to the abdominal appendages. Female crabs with large numbers of eggs attached to their abdomens are called "sponge" crabs. After approximately 2 weeks, the eggs hatch into a planktonic larval form, the zoea. After several zoeal stages, the larvae become megalops, and at the next molt assume the crab appearance.

Adult size is attained in approximately 1 year.

Additional information on the life history, including bibliographies of the literature on the blue crab in North Carolina and in Chesapeake Bay, may be found in Pearson (1951) and Van Engel (1958).

## THE RIVER AND THE CRAB FISHERY

The commercial fishery for crabs on the Neuse River begins approximately 8 miles below New Bern, N. C., and extends downriver into Pamlico Sound. For the purpose of this study, the lower boundary of the river fishery is considered to be 40 miles below New Bern, east of Broad Creek on the north and east of South River on the south bank (Figure 1). All catches below this point are considered to be from the Pamlico Sound fishery. The 40-mile section of river below New Bern is a sluggish coastal stream varying from 1 to 6 miles wide, with a flat gradient to Pamlico Sound. There is virtually no tidal influence in this area although it is subject to fluctuations due to wind.

Trotlines and otter trawls are the major crab fishing gears in the Neuse River. The trotline is a baited line laid on the river bottom, and, as the line is raised, feeding crabs are brought to the surface where they are caught in a dip net. Trotlines usually are fished in 3 to 8 feet of water in the mouths of the tributaries or in the river near the tributaries. Wharton (1954) and Van Engel (1962) further described the trotline and the method of fishing this gear. Most otter trawls are 33 feet across the mouth and are pulled along the bottom in water from 5 to 15 feet deep by trawlers 25 feet in length. Trawls used mainly for catching crabs have cod ends with 4 inches stretched mesh, and trawls fished primarily for shrimp have cod ends with 1¾ inches stretched mesh. In this paper trawls with 4 inches stretched mesh in cod ends are classified as crab trawls and those with the smaller mesh are classified as shrimp trawls. Both crab and shrimp trawls are fished in and near the mouths of Broad and Adams Creeks, South River, and in the vicinity of Oriental (Figure 1).

## MATERIALS AND METHODS

The sources of information used to derive estimates of the crab population in the Neuse River were catch–effort data, data obtained from sampling the catch, and the results of a tagging study.

### *Catch–effort data*

Each fisherman's catch by gear, day, and locality was obtained from crab dealers. Catches by week for trotlines and crab and shrimp trawls are given in Table 1. Crab pots and oyster dredges, which caught 3,527 pounds (mostly in March, April, October, and November), are not included in Table 1. Included in the crab and shrimp trawl catches are 11,141 pounds of soft or peeler crabs. A few female soft crabs are included in the trotline catches. These soft female crabs were mating and were being carried by male crabs which fed on the trotline baits. Therefore, when the mating males were caught, so were the soft female crabs. Generally, trotline fishermen do not separate the few soft crabs when marketing their catch.

Following is the procedure used to standardize the effort for the major types of crabbing gear. Units of trotline, crab trawl, and shrimp trawl effort are recorded by week (Table 1), and each unit represents one trotline or trawl, respectively, fished during 1 day. The average catches per day were 245.8, 350.0, and 261.9 pounds for trotlines, crab trawls, and shrimp trawls. Letting the average catch per day of a trotline represent the catch of a standard fishing unit, the fishing powers (Ricker, 1958) of crab and shrimp trawls relative to the catch of a standard unit were 1.42 and 1.06, respectively (Table 1). Standard fishing units, representative of the effort of crab and shrimp trawls, were calculated by dividing crab trawl and shrimp trawl effort by the respective fishing powers of these gears. The total standard fishing units of the three gears during each week was divided into the total weekly catch to obtain an estimate of the catch per standard unit of effort during each week (Table 1).

### *Tag-and-recovery data*

During 1958, crabs of 5 or more inches in carapace width were tagged and released in the crab fishing areas of the Neuse River (Table 2). All tagged females were adults

TABLE 1.—*Catch statistics of blue crab in the Neuse River by weeks beginning 7 April 1958 and ending 9 November 1958*

| Week | Trotline | | Crab trawl | | | Shrimp trawl | | | Total | | Catch per standard fishing unit |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | Catch | Effort | Catch | Effort | | Catch | Effort | | Catch | Effort | |
| | Pounds | Trotline days or standard fishing units | Pounds | Crab trawl days | Standard fishing units | Pounds | Shrimp trawl days | Standard fishing units | Pounds | Standard fishing units | Pounds |
| 1 | | | 261 | 2 | 3 | | | | 261 | 3 | 87.0 |
| 2 | 154 | 2 | 6,624 | 14 | 20 | | | | 6,778 | 22 | 308.1 |
| 3 | 271 | 4 | 26,698 | 65 | 92 | | | | 26,969 | 96 | 280.9 |
| 4 | 737 | 7 | 15,780 | 91 | 129 | | | | 16,517 | 136 | 121.4 |
| 5 | 1,276 | 9 | 10,356 | 68 | 96 | | | | 11,632 | 105 | 110.8 |
| 6 | 9,252 | 61 | 34,090 | 121 | 172 | | | | 43,342 | 233 | 186.0 |
| 7 | 33,452 | 125 | 39,909 | 123 | 175 | | | | 73,361 | 300 | 244.5 |
| 8 | 33,054 | 169 | 34,493 | 91 | 129 | | | | 67,547 | 298 | 226.7 |
| 9 | 39,674 | 222 | 38,749 | 114 | 162 | 278 | 2 | 2 | 78,701 | 386 | 203.9 |
| 10 | 51,995 | 291 | 36,195 | 109 | 155 | 2,753 | 16 | 17 | 90,943 | 463 | 196.4 |
| 11 | 59,474 | 241 | 65,236 | 133 | 189 | 7,517 | 21 | 22 | 132,227 | 452 | 292.5 |
| 12 | 30,779 | 173 | 30,732 | 86 | 122 | 11,568 | 50 | 53 | 73,079 | 348 | 210.0 |
| 13 | 38,000 | 197 | 12,059 | 50 | 71 | 10,237 | 40 | 42 | 60,296 | 310 | 194.5 |
| 14 | 60,726 | 196 | 15,163 | 36 | 51 | 21,486 | 80 | 85 | 97,375 | 332 | 293.3 |
| 15 | 61,666 | 198 | 23,105 | 35 | 50 | 33,636 | 68 | 72 | 118,407 | 320 | 370.0 |
| 16 | 57,999 | 170 | 18,729 | 35 | 50 | 30,911 | 82 | 87 | 107,639 | 307 | 350.6 |
| 17 | 61,463 | 165 | 16,310 | 33 | 47 | 34,346 | 83 | 88 | 112,119 | 300 | 373.7 |
| 18 | 50,776 | 192 | 6,493 | 21 | 30 | 26,565 | 88 | 93 | 83,834 | 315 | 266.1 |
| 19 | 56,533 | 195 | 7,570 | 21 | 30 | 36,810 | 135 | 143 | 100,913 | 368 | 274.2 |
| 20 | 54,074 | 179 | 3,450 | 14 | 20 | 33,554 | 115 | 122 | 91,078 | 321 | 283.7 |
| 21 | 22,770 | 75 | 2,459 | 9 | 13 | 33,783 | 132 | 140 | 59,012 | 228 | 258.8 |
| 22 | 36,026 | 155 | 1,821 | 4 | 6 | 25,106 | 97 | 103 | 62,953 | 264 | 238.4 |
| 23 | 34,833 | 152 | 3,118 | 5 | 7 | 31,834 | 117 | 124 | 69,785 | 283 | 246.6 |
| 24 | 28,117 | 123 | 1,723 | 4 | 6 | 17,288 | 98 | 104 | 47,128 | 233 | 202.3 |
| 25 | 20,157 | 92 | 867 | 4 | 6 | 17,434 | 121 | 128 | 38,458 | 226 | 170.2 |
| 26 | 7,093 | 42 | | | | 462 | 13 | 14 | 7,555 | 56 | 134.9 |
| 27 | 5,421 | 37 | 12 | 1 | 1 | 1,649 | 31 | 33 | 7,082 | 71 | 99.7 |
| 28 | 8,115 | 38 | | | | 1,953 | 38 | 40 | 10,068 | 78 | 129.1 |
| 29 | | | 225 | 1 | 1 | 516 | 8 | 8 | 741 | 9 | 82.3 |
| 30 | 1,982 | 12 | 631 | 3 | 4 | 1,959 | 20 | 21 | 4,572 | 37 | 123.6 |
| 31 | 212 | 1 | 816 | 3 | 4 | 700 | 5 | 5 | 1,728 | 10 | 172.8 |
| Total | 866,081 | 3,523 | 453,674 | 1,296 | 1,841 | 382,345 | 1,460 | 1,546 | 1,702,100 | 6,910 | |
| Catch per unit of effort (pounds) | | 245.8 | | 350.0 | | | 261.9 | | | | |
| Fishing power in relation to trotline | | 1.00 | | 1.42 | | | 1.06 | | | | |

and would not molt. There was no method of determining whether tagged males were fully grown or whether they would continue to molt. Tagging began the last of April and continued at semimonthly intervals until the end of September. The number of tagged crabs released in each area of the river was based upon the expected abundance in the areas, so that the ratios of tagged to untagged crabs in each area would be approximately equal. Suggestions regarding expected abundance in the areas were obtained from fishermen and from examination of catch records for previous years.

Crabs for tagging were obtained from commercial fishermen. All crabs of the correct width in the catch from a drag or from one or more trotline runs were tagged. At times large quantities of crabs were caught by trawlers and dumped on deck. Since it was not practical to tag all the available crabs in these particular drags and in order to avoid sex or size bias, only crabs occupying a portion of the deck and of the proper size were tagged. Sex and carapace width were recorded before tagging the crabs. A carapace tag (Rounsefell and Everhart, 1953) was attached to each crab with stainless-steel wire, and the crabs were released in the area of capture. The numbered tags carried a reward (25 cents) notice and the name and address of the tagging institution.

A list of the commercial crab fishermen on the river was obtained from the crab dealers. Tag return envelopes were enclosed with letters sent to these fishermen informing them of the tagging study. Newspaper articles and reward notices displayed by crab dealers and at crab picking plants gave added publicity to the tagging program. In addition to tag

TABLE 2.—*Number of tagged crabs released at various locations on the Neuse River and Pamlico Sound, and the tag returns from these releases*

| Location released | Released | | Returned | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Males | Females | Males | | Females | | Total | |
| | Number | Number | Number | Percentage | Number | Percentage | Number | Percentage |
| Neuse River | | | | | | | | |
| Goose Creek | 741 | 68 | 242 | 33 | 17 | 25 | 259 | 32 |
| Slocum Creek | 132 | 16 | 54 | 41 | 1 | 6 | 55 | 37 |
| Beards Creek | 711 | 108 | 316 | 44 | 21 | 19 | 337 | 41 |
| Oriental | 1,116 | 302 | 307 | 28 | 51 | 17 | 358 | 25 |
| Adams Creek | 182 | 108 | 76 | 42 | 33 | 30 | 109 | 38 |
| South River | 67 | 38 | 20 | 30 | 4 | 10 | 24 | 23 |
| Total | 2,949 | 640 | 1,015 | 34 | 127 | 20 | 1,142 | 32 |
| Pamlico Sound | | | | | | | | |
| Swanquarter | 405 | 124 | 72 | 18 | 17 | 14 | 87 | 17 |
| Stumpy Point | 484 | 322 | 98 | 20 | 50 | 16 | 148 | 18 |
| Avon | 403 | 437 | 114 | 28 | 100 | 23 | 214 | 25 |
| Ocracoke | 27 | 368 | 7 | 26 | 24 | 6 | 31 | 8 |
| Harbor Island | 31 | 63 | 6 | 19 | 11 | 17 | 17 | 18 |
| Total | 1,350 | 1,314 | 297 | 22 | 202 | 15 | 499 | 19 |

returns by mail, monthly visits were made to crab dealers and picking plants to obtain recovered tags. Fishermen were contacted frequently for tag returns, and a canvass of each fisherman at the end of the season also accounted for numerous tag returns.

Crabs 5 or more inches in carapace width were also tagged in Pamlico Sound (Table 2). The purpose of this phase of the study was to determine if commercial-size crabs moved from Pamlico Sound into the Neuse River. Approximately 200 crabs, obtained from commercial fishermen, were tagged at bimonthly intervals, beginning in April and continuing into October, in each of five areas of Pamlico Sound. The smaller numbers of crabs tagged at Swanquarter, Ocracoke, and Harbor Island resulted from the intermittent fishery in these areas. Bimonthly contact with the crab fishermen, as well as newspaper articles and reward posters in crab plants situated around the sound, facilitated the return of tags.

### *Catch sampling*

Between April and September 1958, 30 samples of crabs caught by commercial fishermen on trotlines and in trawls were examined to obtain estimates of the sex ratio in the entire catch and the ratio of precommercial- to commercial-size crabs. These samples were taken monthly in five areas of the river, provided a fishery was in operation. Samples were obtained before the fishermen released any of the smaller crabs.

Sampling was continued during the 1959 crabbing season, and, in addition to sex and size, individual live weights also were obtained. Two types of samples were obtained from the fishermen. One type was obtained before the fisherman culled or released the small crabs, and the other after culling.

## FACTORS AFFECTING ABUNDANCE

Two main factors, other than catch, affected the size of the commercial crab population in the Neuse River. These were: 1) movement of commercial-size female crabs out of the river, and 2) recruitment. The importance of natural mortality and other factors that might have affected population size will be discussed in a later section.

### *Movement*

Tag returns indicated that during the crabbing season in the river commercial-size crabs of both sexes did not move from Pamlico Sound to the river and that commercial-size male crabs did not move from the river to the sound. However, the returns did indicate movement of commercial-size female crabs from the river to the sound. Movement of females downriver into the sound was also suggested by the samples from the crab catch in the river and from observations of catches made in the river and in Pamlico Sound.

Of the 2,664 crabs tagged in five areas of Pamlico Sound in 1958, 499 or 19% were recovered (Table 2). Twenty-nine of these recoveries, 18 males and 11 females, were made more than 5 miles from the vicinity of release. All of these 29 recoveries were recaptured in the sound, generally to the south or southeast of the area of tagging. No tagged crabs released in Pamlico Sound were recaptured in the Neuse River.

Of the 2,949 tagged males released during 1958 in the river, 1,015 or 34% were recovered (Table 2). Commercial crab fishermen operating in the river recaptured 899 males in 1958, 19 in 1959, and 1 each in 1960 and 1961. Six males were recaptured outside the river in 1958. Only one of these recoveries, made near the mouth of the river in July, indicated that males perhaps moved from the river during the crab-fishing season. The remaining five recoveries were made in late fall and winter near the mouth of the river, in Pamlico Sound. Also during 1958, 32 crabs were recovered in the river by sport fishermen and seven by commercial fishermen fishing for species other than crabs. For 50 returns, data were not available on location, or date of capture, or both.

Of the 640 tagged females released in the river, 127 or 20% were recovered (Table 2). Ninety-nine were recovered in the river in 1958 by crab fishermen, but none were recovered there in 1959, 1960, or 1961. Seven females were recaptured in 1958 and six in 1959 in Pamlico and Core Sounds. One female was recovered in the ocean at Cape Lookout in 1961 (Figure 1). Sport fishermen caught two females in the river during 1958, and one was captured by an oyster dredge fisherman in the fall. For 11 returns, data were not available on location or date of capture, or both.

In addition to the seven tag returns from mature females released in the river and recaptured in the sounds in 1958, the following circumstantial evidence also suggests movement of mature female crabs downriver:

1) Marketing of sponge crabs was illegal in 1958, and crab fishing was usually terminated in areas where these crabs predominated. During late spring and summer, the presence of large numbers of sponge crabs in southeast Pamlico Sound caused a halt in the crab fishery in this area. Therefore, although only a few of the tagged mature females released in the river were recovered in Pamlico Sound, the lack of a substantial fishery in the sound during summer, suggests that these recoveries might represent a larger percentage of females that emigrated from the river.

2) Recently matured females were present in the low salinity water (of the river) and sponge crabs in the higher salinity waters (of the sounds). These were the same conditions found in other areas where downriver migration of mature females occurs (Darnell, 1959; Porter, 1956; Truitt, 1939).

3) Both females and males were recovered from the river for 2 weeks after release of tagged crabs of both sexes in the river, but subsequently only males were taken in the river.

Although sport and commercial fishermen not fishing for crabs accounted for 42 recoveries, the catch of hard crabs retained by these fishermen was small and was not included with the commercial fishery catch–effort data.

### *Recruitment*

Estimates of daily recruitment were calculated from the percentages of precommercial crabs in the 30 samples of unculled catches obtained in 1958. From samples of unculled as well as culled catches in 1959, the minimum size of crabs sold by the fishermen was estimated to be approximately 4.5 inches carapace width. This figure was applied to the 1958 samples, and the crabs between 3.4 and 4.5 inches were designated precommercial-size crabs. The average time for precommercial-size crabs to shed and become commercial-size crabs was considered 17.5 days. The procedure for estimating recruitment from ratios of precommercial- to commercial-size crabs was as follows:

1) During May and June of 1961, studies, reported by Davis (unpublished), were conducted near the mouth of Adams Creek (Figure 1) to determine whether 3.4 inches

and 17.5 days were, respectively, reasonable estimates of the lower limit of precommercial-size crabs and the average molting time. The crabs used in the experiments were caught by commercial fishermen in Adams Creek and South River. No selection was made for crabs in any particular stage of the intermolt cycle. During May and June a total of 251 crabs was placed in compartmented floats at Adams Creek. Sixty-three crabs died without molting, 124 molted (52 males and 72 females), and 64 were alive and unmolted at the end of the experiments on 30 June. Before molting, the 52 male crabs averaged 3.4 inches in width (range, 2.4 to 4.5 inches), and after molting averaged 4.4 inches (range, 3.2 to 5.7 inches). The 72 females averaged 3.6 inches (range, 2.4 to 4.6 inches) before molting and 4.9 inches (range, 3.2 to 6.4 inches) after molting. These results and those of Gray and Newcombe (1939), where Chesapeake Bay crabs averaging 3.4 inches subsequently averaged 4.5 inches after molting, suggest that 3.4 inches is a good estimate of the actual lower limit of precommercial-size crabs in the Neuse River which will be of commercial size (4.5 inches or wider) after molting.

2) Of the 251 crabs used in the experiments at Adams Creek, 170 were put in the floats in May and 81 on 14 June. Of the 170 crabs placed in floats in May, 92 molted, 46 died, and 32 were alive and had not molted by 30 June. Both males and females that molted averaged 8.9 days to molt. The time-to-shed distribution for the crabs that molted (73% of the 92 crabs molted within 7 days) suggests that when the crabs were first placed in the floats there were unequal numbers in various stages of the intermolt cycle. However, if continuous captivity depressed the molting process of crabs that would molt later in the experiment more so than those that would molt shortly after beginning the experiment, and if the mortality rate increased with length of captivity, then these factors could also cause the time-to-shed distribution for the crabs that molted to be positively skewed. Therefore, because of possible effects of captivity on the time-to-shed distribution the arithmetic mean of the times-to-shed (8.9 days), rather than another measure such as the median number of days, was considered the best estimate representative of the average time-to-shed for precommercial crabs in the Neuse River.

It was assumed (1) that the crabs in the experiments at Adams Creek were representative of the precommercial crabs in the Neuse River and its tributaries, and (2) that 8.9 days was the average time for precommercial-size crabs to shed. Approximately twice the value of 8.9, 17.5 days, was considered the total time to shed for precommercial crabs. Therefore, assuming that in a sample of crabs 3.4 to 4.5 inches carapace width there are equal numbers of crabs in all stages of the molt cycle, then 1/17.5 of these crabs could be expected to shed each day.

The results of the experiment at Adams Creek have been used to attempt a justification for an average molting rate per day of 0.0571 (1/17.5) for precommercial crabs. This rate, based on experiments where 46% of the crabs died or did not molt, may be incorrect. However, a comparison of recruitment rates calculated from a molting rate of 0.0571 per day agreed with the recruitment rates calculated from the ratio of soft to hard crabs in the catch (see Discussion).

3) From the crab weight–width relation estimated from the samples of crabs obtained in 1959, the weight was estimated of the 1958 samples of precommercial-size crabs after molting (Table 3). This estimated weight of male and female recruits for each sample was reduced by an estimate of mortality during molting (7%), and by a factor of unavailability to the fishery for commercial-size females (0.44). The estimate of 7% mortality during molting was obtained from studies by Robertson (unpublished). Although he worked with crabs smaller than precommercial sizes, he found an almost constant 7% mortality between molts. The factor of 0.44 for relative unavailability of females to the fishery was

TABLE 3.—*Estimated daily recruitment rates calculated from 30 catch samples, Neuse River, 1958*

| Area | Date | Number of precommercial-size crabs | | Estimated weight of precommercial crabs after molting[1] (grams) | | | Estimated weight of commercial-size crabs (grams) | Ratio[2] | Daily recruitment rate (percentage) |
|---|---|---|---|---|---|---|---|---|---|
| | | Male | Female | Male | Female | Total | | | |
| Goose Creek | 23 May | 54 | 26 | 6,932 | 1,432 | 8,364 | 11,944 | 0.700 | 4.0 |
| " " | 9 July | 37 | 6 | 4,943 | 310 | 5,253 | 12,333 | 0.430 | 2.4 |
| " " | 17 July | 36 | 14 | 4,350 | 716 | 5,066 | 11,543 | 0.439 | 2.5 |
| Beards Creek | 19 June | 49 | 24 | 6,213 | 1,309 | 7,522 | 5,966 | 1.261 | 7.2 |
| " " | 11 July | 25 | 9 | 3,116 | 216 | 3,332 | 12,266 | 0.272 | 1.6 |
| " " | 14 Aug. | 23 | 15 | 2,837 | 808 | 3,645 | 12,784 | 0.285 | 1.6 |
| " " | 3 Sept. | 27 | 23 | 3,450 | 1,187 | 4,637 | 10,404 | 0.446 | 2.5 |
| " " | 24 Apr. | 20 | 16 | 2,295 | 853 | 3,148 | 11,491 | 0.274 | 1.6 |
| " " | 13 May | 13 | 12 | 1,848 | 681 | 2,529 | 11,258 | 0.225 | 1.3 |
| " " | 22 May | 20 | 3 | 2,569 | 174 | 2,743 | 17,976 | 0.152 | 0.9 |
| Oriental | 5 June | 42 | 34 | 5,107 | 1,804 | 6,911 | 7,409 | 0.933 | 5.3 |
| " | 1 July | 31 | 33 | 4,047 | 1,711 | 5,758 | 11,528 | 0.499 | 2.8 |
| " | 30 July | 18 | 10 | 2,532 | 541 | 3,073 | 16,799 | 0.183 | 1.0 |
| " | 26 Aug. | 17 | 17 | 2,134 | 900 | 3,034 | 16,114 | 0.188 | 1.1 |
| " | 24 Sept. | 9 | 8 | 1,150 | 443 | 1,593 | 15,339 | 0.104 | 0.6 |
| " | 9 May | 22 | 21 | 2,914 | 1,109 | 4,023 | 7,895 | 0.510 | 2.9 |
| " | 2 June | 17 | 25 | 2,159 | 1,281 | 3,440 | 11,618 | 0.296 | 1.9 |
| " | 30 June | 24 | 13 | 3,080 | 701 | 3,781 | 11,549 | 0.327 | 1.9 |
| " | 30 July | 23 | 33 | 2,783 | 1,798 | 4,581 | 12,045 | 0.380 | 2.2 |
| " | 29 Aug. | 14 | 18 | 1,713 | 965 | 2,678 | 12,470 | 0.215 | 1.2 |
| Adams Creek | 29 Apr. | 20 | 20 | 2,496 | 1,012 | 3,508 | 9,384 | 0.374 | 2.1 |
| " " | 23 June | 31 | 38 | 3,705 | 1,921 | 5,626 | 8,134 | 0.692 | 4.0 |
| " " | 25 July | 6 | 4 | 839 | 433 | 1,272 | 10,738 | 0.118 | 0.7 |
| " " | 20 Aug. | 10 | 14 | 1,258 | 729 | 1,987 | 11,408 | 0.174 | 1.0 |
| " " | 18 Sept. | 18 | 25 | 2,136 | 1,268 | 3,404 | 13,488 | 0.252 | 1.4 |
| South River | 23 July | 25 | 24 | 3,208 | 1,261 | 4,469 | 12,855 | 0.348 | 2.0 |
| " " | 27 May | 12 | 13 | 1,502 | 628 | 2,130 | 7,993 | 0.266 | 1.5 |
| " " | 26 June | 12 | 17 | 1,549 | 832 | 2,381 | 13,660 | 0.174 | 1.0 |
| " " | 21 Aug. | 18 | 27 | 2,085 | 1,392 | 3,477 | 11,618 | 0.299 | 1.7 |
| " " | 18 Sept. | 10 | 27 | 1,140 | 1,434 | 2,574 | 10,684 | 0.241 | 1.4 |

[1] Reduced by 7% for estimated mortality while molting, and the females reduced by an additional 44% (see text).

[2] Consists of the estimated weight of precommercial crabs after molting divided by the weight of commercial-size crabs.

obtained from the tagging study in the river. Of the females released in the river, 18% were recaptured in the river in 1958, compared with a 32% return for tagged males. The difference between the two percentages (14) divided by the percentage return for tagged males (32) was the estimate, 0.44, of the proportion of precommercial-size female crabs that after molting escaped the fishery and moved from the river. Neither varying ratios of the number of male to female crabs tagged during the fishing season nor from the different fishing areas, could have caused the unequal percentage returns from the sexes.

Briefly, the method of calculating recruitment rates from a catch sample was to estimate the weights of precommercial males and females after molting, reduce them by 7%, and then further reduce the weight of the females by 44%. These weights were then divided by the estimated weight of commercial-size crabs in the samples and by 17.5 to obtain estimates of daily recruitment rates (Table 3). The calculated rates are estimates of the percentage increase in the crab population of commercial size in the various fishing areas on the days of sampling. In Table 4 are unweighted average estimates of the daily recruitment rates shown in Table 3 during semimonthly periods from 1 May to 30 September.

## POINT ESTIMATES OF POPULATION SIZE

Three methods, designated as the Leslie, Alternate, and Parker methods, were used to obtain point estimates of the size of the commercial crab population in the Neuse River during 1958.

### *Leslie method*

This method (Leslie and Davis, 1939; Ricker, 1958) of estimating population size was applied to the 1958 Neuse River crab catch and effort data. It "involves plotting the catch per unit effort against cumulative catch over a period of time" (Ricker, 1958). If the plot gives an acceptably straight line, initial population size and catchability can be estimated.

TABLE 4.—*Estimates of daily recruitment rates during semimonthly periods, Neuse River, 1958*

| Period | Daily recruitment rate (percentage) |
|---|---|
| 1–15 May | 2.1 |
| 16–31 May | 2.1 |
| 1–15 June | 3.5 |
| 16–30 June | 3.5 |
| 1–15 July | 2.3 |
| 16–31 July | 1.6 |
| 1–15 August | 1.6 |
| 16–31 August | 1.2 |
| 1–15 September | 2.5 |
| 16–30 September | 1.1 |

TABLE 5.—*Percentage by weight of commercial-size crabs in catch samples, Neuse River, 1958*

| Area | Gear | Apr. | May | June | July | Aug. | Sept. |
|---|---|---|---|---|---|---|---|
| Beards Creek | Trotline | | | 74 | 90 | 80 | 77 |
| | Crab trawl | 88 | 86 | —[1] | —[1] | —[1] | —[1] |
| Goose Creek | Trotline | | 84 | | 85 | | |
| | | —[1] | 74 | | 83 | | |
| Adams Creek | Shrimp trawl | —[1] | —[1] | | 39 | 65 | 65 |
| | Crab trawl | 73 | | 73 | | —[1] | —[1] |
| Oriental | Trotline | | | 71 | 77 | 77 | 96 |
| | | | | | 82 | | |
| | Crab trawl | | 85 | 78 | | | |
| | | | | 89 | | | |
| | Shrimp trawl | —[1] | —[1] | | 74 | 76 | |
| South River | Trotline | —[1] | | | 83 | | |
| | Shrimp trawl | —[1] | —[1] | | | 79 | 58 |
| | Crab trawl | | 75 | 66 | | —[1] | —[1] |
| Average | | 80 | 81 | 75 | 77 | 75 | 74 |

[1] No crabs caught by the specified gear during the month.

When applying this method, it is necessary that (1) changes in availability and vulnerability be negligible as the fishing season progresses, (2) movements of the population out of the fishing area and of other populations into the area also be negligible, and (3) recruitment either balance natural mortality and predation, or that these factors be insignificant during the fishing season. For the present, changes in availability, vulnerability, and therefore catchability will be considered insignificant, and natural mortality and predation will be considered negligible. Because of the possible bias these factors might introduce into the various methods of population estimation that will be presented, and because some assumptions were not completely fulfilled, they will be more fully discussed in a later section of this paper.

To satisfy the condition for no movement, only catch and effort data for males were used because the tagging and catch sampling studies indicated commercial-size females moved out of the river while the fishery was operating. To correct for the weight of male recruits in the weekly catches of male crabs after a particular day ($t = 0$), the proportion of recruits was first estimated and then subtracted from the weekly catches. The remainder of the catch each week was considered to be from the male population at $t = 0$, and was supposedly free of recruits. Estimates of the number of standard fishing units for each week were calculated, and these data, together with the catch data, were used in the Leslie method to estimate the population of male crabs.

Immediately following are the methods used to estimate the weight of male crabs in the weekly catches, the procedure to correct these catches for recruits, and the estimation of population size.

The estimated percentage by weight of commercial-size males to the total weight of males and females was calculated for each of the 30 catch samples (Table 5). The number of commercial-size crabs in a sample ranged from 52 to 119. For each of the three major types of gear fished, the estimated monthly catch of males in the various areas of the river was obtained by multiplying the total catch in the area by the estimate of the percentage of males estimated from the 30 catch samples. However, only the calculations for estimating the catch of male crabs by crab trawls is shown (Table 6). Where a sample of crabs was not taken in an area during a month or from the particular type of gear, the average proportion of males from all samples taken during the month was used as the estimate of the proportion of male crabs in the monthly catch.

The ratios of males in the total catch by gear for each month were then applied to the total catch by each type gear for each week (Table 7). From this the total male catch by week was obtained (last column of Table 7). Although the catches of male crabs by gear and week (Table 7) implies completeness of the data, they were based on only the 30 catch samples obtained from the commercial fishery.

Estimates of daily recruitment rate for

Table 6.—*Calculation of pounds of commercial-size male crabs caught by crab trawls, Neuse River, 1958*

| Area | | Apr. | May | June | July | Aug. | Sept. | Oct. | Nov. |
|---|---|---|---|---|---|---|---|---|---|
| Beards Creek | Total catch | 8,174 | 13,329 | | | | | | |
| | Ratio males | 0.88 | 0.85 | | | | | | |
| | Catch males | 7,193 | 11,330 | | | | | | |
| Adams Creek and South River | Total catch | 310 | 9,341 | 9,562 | 8,572 | | | | |
| | Ratio males | 0.80[1] | 0.81[2] | 0.75[3] | 0.77[4] | | | | |
| | Catch males | 248 | 7,566 | 7,172 | 6,600 | | | | |
| Oriental | Total catch | 37,402 | 99,655 | 166,195 | 71,823 | 20,098 | 7,529 | 868 | 816 |
| | Ratio males | 0.80[1] | 0.85 | 0.84 | 0.77[4] | 0.75[5] | 0.74[6] | 0.74[6] | 0.74[6] |
| | Catch males | 29,922 | 84,707 | 139,604 | 55,304 | 15,074 | 5,571 | 642 | 604 |
| Total catch | | 45,886 | 122,325 | 175,757 | 80,395 | 20,098 | 7,529 | 868 | 816 |
| Catch of males | | 37,363 | 103,603 | 146,776 | 61,904 | 15,074 | 5,571 | 642 | 604 |
| Proportion of males | | 0.81 | 0.85 | 0.84 | 0.77 | 0.75 | 0.74 | 0.74 | 0.74 |

[1] Average of 2 samples taken in month of April.
[2] Average of 5 samples taken in month of May.
[3] Average of 6 samples taken in month of June.
[4] Average of 8 samples taken in month of July.
[5] Average of 5 samples taken in month of August.
[6] Average of 4 samples taken in month of September.

males to the commercial-size male population were calculated from the 30 catch samples in the same manner as the recruitment rate estimates presented in Table 3 for both males and females. The estimates of daily recruitment rate for males were applied to the catches of male crab by area, gear, and month. Only the calculations of the estimated catch of male recruits by trotlines are shown (Table 8). When estimates of daily recruitment rate were not available for males in a particular area or by a particular gear, the average rate from all samples during the month was used. The recruitment rate for a month was asssumed to be the number of days in a month multiplied by the daily rate. The monthly rates were divided in half before applying them to the monthly male catches. This was necessary to give a better estimate of the pounds of recruits in any monthly catch as the proportion of recruits in the daily catch at the beginning of the month was negligible, but the last day of the month was at least equal to the cumulative daily recruitment rate during the month minus recruit mortality previous to the last day of the month. The cumulative daily recruitment rate for a month divided by two was considered the best simple ratio to apply to the monthly catch. When the catch of male recruits was estimated to be greater than the catch in a month for an area, the recruits were considered to equal the monthly catch. An example of this is the estimate of the recruits in the trotline catch at Beards Creek during June (Table 8).

Assuming a daily recruitment rate of 0.017 at Beards Creek during April (Table 8), the monthly recruitment rate should be 0.017 × 30, which equals 0.510. However, the trotline fishery began on 18 April in this area, and therefore the daily rate (0.017) was multiplied by 13, the number of days from 18 to 30 April, inclusive, to obtain the estimate of the monthly recruitment rate (0.221) during the period in April when trotlines operated at Beards Creek. This figure was halved to give the estimate (0.110) of the ratio of recruits in the catch. The product of the catch (862 pounds) multiplied by 0.110, gives an estimate of the crabs recruited in April that were caught during the same month (95 pounds).

In the last three lines of Table 8 are estimates for each month of the total catch of male crabs by trotlines, the male crabs recruited during the month and caught the same month, and the proportion of the trotline catch of males recruited and caught during the month. Proportions of this kind for the catches by shrimp and crab trawls were then calculated (not shown).

To obtain the proportion of recruits in the weekly catches (columns 3, 6, 9; Table 9), the proportions in the monthly catches (last line of Table 8 for the trotline catches) were divided by 30 or 31 and the quotient multiplied by 7. In the last three columns of Table 9 are estimates of the weekly catch by all gears of male crabs, the male crabs recruited during each week and caught the same week,

TABLE 7.—*Estimated pounds of commercial-size male crabs caught each week in 1958*

| Beginning of week | Trotline | | | Crab trawl | | | Shrimp trawl | | | Total catch of males |
|---|---|---|---|---|---|---|---|---|---|---|
| | Catch | Ratio of males | Catch of males | Catch | Ratio of males | Catch of males | Catch | Ratio of males | Catch of males | |
| 7 April | | | | 261 | 0.81 | 211 | | | | 211 |
| 14 April | 154 | 0.80 | 123 | 6,624 | 0.81 | 5,365 | | | | 5,488 |
| 21 April | 271 | 0.80 | 217 | 26,698 | 0.81 | 21,625 | | | | 21,842 |
| 28 April | 737 | 0.80 | 590 | 15,780 | 0.83 | 13,097 | | | | 13,687 |
| 5 May | 1,276 | 0.80 | 1,021 | 10,356 | 0.85 | 8,803 | | | | 9,824 |
| 12 May | 9,252 | 0.80 | 7,402 | 34,090 | 0.85 | 28,976 | | | | 36,378 |
| 19 May | 33,452 | 0.80 | 26,762 | 39,909 | 0.85 | 33,923 | | | | 60,685 |
| 26 May | 33,054 | 0.79 | 26,113 | 34,493 | 0.85 | 29,319 | | | | 55,432 |
| 2 June | 39,674 | 0.74 | 29,359 | 38,749 | 0.84 | 32,549 | 278 | 0.75 | 208 | 62,116 |
| 9 June | 51,995 | 0.74 | 38,476 | 36,195 | 0.84 | 30,404 | 2,753 | 0.75 | 2,065 | 70,945 |
| 16 June | 59,474 | 0.74 | 44,011 | 65,236 | 0.84 | 54,798 | 7,517 | 0.75 | 5,638 | 104,447 |
| 23 June | 30,779 | 0.74 | 22,776 | 30,732 | 0.84 | 25,815 | 11,568 | 0.75 | 8,676 | 57,267 |
| 30 June | 38,000 | 0.82 | 31,160 | 12,059 | 0.78 | 9,406 | 10,237 | 0.66 | 6,756 | 47,322 |
| 7 July | 60,726 | 0.83 | 50,402 | 15,163 | 0.77 | 11,676 | 21,486 | 0.64 | 13,751 | 75,829 |
| 14 July | 61,666 | 0.83 | 51,183 | 23,105 | 0.77 | 17,791 | 33,636 | 0.64 | 21,527 | 90,501 |
| 21 July | 57,999 | 0.83 | 48,139 | 18,729 | 0.77 | 14,421 | 30,911 | 0.64 | 19,783 | 82,343 |
| 28 July | 61,463 | 0.80 | 49,170 | 16,310 | 0.76 | 12,396 | 34,346 | 0.68 | 23,355 | 84,921 |
| 4 Aug. | 50,776 | 0.77 | 39,098 | 6,493 | 0.75 | 4,870 | 26,565 | 0.74 | 19,658 | 63,626 |
| 11 Aug. | 56,533 | 0.77 | 43,530 | 7,570 | 0.75 | 5,678 | 36,810 | 0.74 | 27,239 | 76,447 |
| 18 Aug. | 54,074 | 0.77 | 41,637 | 3,450 | 0.75 | 2,588 | 33,554 | 0.74 | 24,830 | 69,055 |
| 25 Aug. | 22,770 | 0.77 | 17,533 | 2,459 | 0.75 | 1,844 | 33,783 | 0.74 | 24,999 | 44,376 |
| 1 Sept. | 36,026 | 0.80 | 28,821 | 1,821 | 0.74 | 1,348 | 25,106 | 0.68 | 17,072 | 47,241 |
| 8 Sept. | 34,833 | 0.80 | 27,866 | 3,118 | 0.74 | 2,307 | 31,834 | 0.68 | 21,647 | 51,820 |
| 15 Sept. | 28,117 | 0.80 | 22,494 | 1,723 | 0.74 | 1,275 | 17,288 | 0.68 | 11,756 | 35,525 |
| 22 Sept. | 20,157 | 0.80 | 16,126 | 867 | 0.74 | 642 | 17,434 | 0.68 | 11,855 | 28,623 |
| 29 Sept. | 7,093 | 0.76 | 5,391 | | | | 462 | 0.72 | 333 | 5,724 |
| 6 Oct. | 5,421 | 0.74 | 4,012 | 12 | 0.74 | 9 | 1,649 | 0.74 | 1,220 | 5,241 |
| 13 Oct. | 8,115 | 0.74 | 6,005 | | | | 1,953 | 0.74 | 1,445 | 7,450 |
| 20 Oct. | | | | 225 | 0.74 | 166 | 516 | 0.74 | 382 | 548 |
| 27 Oct. | 1,982 | 0.74 | 1,467 | 631 | 0.74 | 467 | 1,959 | 0.74 | 1,450 | 3,384 |
| 3 Nov. | 212 | 0.74 | 157 | 816 | 0.74 | 604 | 700 | 0.74 | 518 | 1,279 |
| Total | 866,081 | | 681,041 | 453,674 | | 372,373 | 382,345 | | 266,163 | 1,319,577 |

and the ratio of these recruits to the total weekly catch of males.

After subtracting the catch of recruits to the male population in a given week from the catch of this week, the remainder represents the catch during the week from the population present at the beginning of the week. This residual can be partitioned into the catch from the population present a week earlier, and the catch of recruits that entered the population the week previous. Beginning with the catch of males during the week of 12–18 May, and applying the estimated weekly ratios of male recruits (last column of Table 9), the catch of recruits during each week was obtained (Table 10). The catch of males during the week of 19–25 May is used as an example to illustrate the partitioning of weekly catches in Table 10. An estimated 60,685 pounds of male crabs were caught, and the best simple estimate of the proportion of the catch of crabs recruited and caught during the week was 0.076 of the catch (week 7, Table 9), or 4,612 pounds. The remaining 56,073 pounds of the catch of male crabs during the week 19–25 May was estimated to be from the population present just prior to 19 May. From this 56,073 pounds can be extracted an estimate of the catch of the crabs recruited to the population in the week 12–18 May. Recruits during the week ending 18 May were estimated to have equaled 0.156 of the population at the beginning of the week. The figure 0.156 is double the estimated proportion of crabs caught during week 6 (12–18 May, last column of Table 9) that were recruited during the sixth week, 12–18 May. It was assumed that the recruitment rate for a week was double the proportion of the catch caught during the week that was recruited the same week. Therefore, the following week, 19–25 May, the catch of crabs recruited during the week previous was estimated to be 15.6% of 56,073 pounds, or 8,747 pounds. The residual of 47,326 pounds is the estimate of crabs, caught during the week of 19–25 May, that were from the commercial male population present just prior to 12 May (Table 10). In Table 10 are listed the estimated male catches each week (column 3), the estimated proportion of recruits each week in the catch of residuals (column 5), the pounds of crabs caught each week that were recruited to the population in a given week (column 6), and

TABLE 8.—*Calculation of the catch of male recruits by trotlines, 1958*

| Area | | Apr. | May | June | July | Aug. | Sept. | Oct. | Nov. |
|---|---|---|---|---|---|---|---|---|---|
| Beards Creek | Total male catch | 862 | 21,926 | 49,701 | 62,792 | 30,506 | 16,043 | 1,116 | |
| | Daily rec. rate[1] | 0.017[6] | 0.021[7] | 0.081 | 0.016 | 0.016 | 0.025 | 0.013[11] | |
| | Mon. rec. rate[2] | 0.221 | 0.651 | 2.430 | 0.496 | 0.496 | 0.750 | 0.130 | |
| | % rec. catch[3] | 11.0 | 32.6 | 121.5 | 24.8 | 24.8 | 37.5 | 6.5 | |
| | Rec. lbs.[4] | 95 | 7,148 | 49,701 | 15,572 | 7,565 | 6,016 | 72 | |
| Goose Creek | Total male catch | | 12,094 | 26,547 | 46,226 | 32,068 | 27,131 | 7,074 | |
| | Daily rec. rate[1] | | 0.045 | 0.035[8] | 0.026 | 0.012[10] | 0.013[11] | 0.013[11] | |
| | Mon. rec. rate[2] | | 0.810 | 1.050 | 0.806 | 0.372 | 0.390 | 0.390 | |
| | % rec. catch[3] | | 40.5 | 52.5 | 40.3 | 18.6 | 19.5 | 19.5 | |
| | Rec. lbs.[4] | | 4,898 | 13,937 | 18,629 | 5,965 | 5,290 | 1,379 | |
| Slocum Creek | Total male catch | | 7,882 | 18,003 | 16,657 | 4,005 | | | |
| | Daily rec. rate[1] | | 0.021[7] | 0.035[8] | 0.018[9] | 0.012[10] | | | |
| | Mon. rec. rate[2] | | 0.567 | 1.050 | 0.558 | 0.216 | | | |
| | % rec. catch[3] | | 28.4 | 52.5 | 27.9 | 10.8 | | | |
| | Rec. lbs.[4] | | 2,238 | 9,452 | 4,647 | 432 | | | |
| Oriental | Total male catch | 67 | 12,191 | 18,016 | 67,164 | 45,187 | 30,129 | 1,005 | |
| | Daily rec. rate[1] | 0.017[6] | 0.021[7] | 0.055 | 0.018 | 0.010 | 0.004 | 0.013[11] | |
| | Mon. rec. rate[2] | 0.119 | 0.651 | 1.650 | 0.558 | 0.310 | 0.120 | 0.130 | |
| | % rec. catch[3] | 6.0 | 32.6 | 82.5 | 27.9 | 15.5 | 6.0 | 6.5 | |
| | Rec. lbs.[4] | 4 | 3,974 | 14,863 | 18,739 | 7,004 | 1,808 | 6.5 | |
| South River | Total male catch | | 4,016 | 18,465 | 24,662 | 22,474 | 13,512 | 3,373 | |
| | Daily rec. rate[1] | | 0.021[7] | 0.035[8] | 0.017 | 0.012[10] | 0.013[11] | 0.013[11] | |
| | Mon. rec. rate[2] | | 0.231 | 1.050 | 0.527 | 0.372 | 0.390 | 0.221 | |
| | % rec. catch[3] | | 11.6 | 52.5 | 26.4 | 18.6 | 19.5 | 11.0 | |
| | Rec. lbs.[4] | | 466 | 9,694 | 6,511 | 4,180 | 2,635 | 371 | |
| Lower Broad Creek | Total male catch | | 3,144 | 8,850 | 8,929 | 7,888 | 11,691 | 1,345 | 157 |
| | Daily rec. rate[1] | | 0.021[7] | 0.035[8] | 0.018[9] | 0.012[10] | 0.013[11] | 0.013[11] | 0.013[11] |
| | Mon. rec. rate[2] | | 0.525 | 1.050 | 0.558 | 0.372 | 0.390 | 0.403 | 0.052 |
| | % rec. catch[3] | | 26.2 | 52.5 | 27.9 | 18.6 | 19.5 | 20.2 | 2.6 |
| | Rec. lbs.[4] | | 824 | 4,646 | 2,491 | 1,467 | 2,280 | 272 | 4 |
| Clubfoot Creek | Total male catch | | | 357 | | | | | |
| | Daily rec. rate[1] | | | 0.035[8] | | | | | |
| | Mon. rec. rate[2] | | | 0.525 | | | | | |
| | % rec. catch[3] | | | 26.2 | | | | | |
| | Rec. lbs.[4] | | | 94 | | | | | |
| | Total male catch | 929 | 61,253 | 139,939 | 226,430 | 142,128 | 98,506 | 13,913 | 157 |
| | Rec. lbs.[4] | 99 | 19,548 | 102,387 | 66,589 | 26,613 | 18,029 | 2,159 | 4 |
| | Mon. prop. rec.[2] | 0.106 | 0.319 | 0.732 | 0.294 | 0.187 | 0.183 | 0.155 | 0.025 |

[1] Estimated daily recruitment rate.

[2] Estimated monthly recruitment rate (based on number of days from the start of fishing in the month to the end of the month, or to the end of fishing in the month).

[3] Estimated per cent of recruits in catch.

[4] Estimated pounds of males in the catch that were recruited during the month.

[5] Estimated proportion of male crabs in the catch that were recruited during the month.

[6] Average of 2 samples taken in month of April.

[7] Average of 5 samples taken in month of May.

[8] Average of 6 samples taken in month of June.

[9] Average of 8 samples taken in month of July.

[10] Average of 5 samples taken in month of August.

[11] Average of 4 samples taken in month of September.

the estimated decreasing catch of crabs (residuals) from the population present each week prior to any given week (column 7). Although Table 10 shows the partitioning of catches from weeks 6 to 13, the same procedure was followed for the catches to and including week 25, 22–28 September.

Estimates of male abundance at the beginning of each week, 12–18 May (week 6) to 28 July–3 August (week 17), were calculated by applying the Leslie method to the catches in the following weeks from the male population at a given time. Using the following notation:

$t$ is the variable associated with week,

$N_0$ is the population of commercial-size crabs at the beginning of week $t = 1$,

$C_t$ is the catch of crabs from population $N_0$, during week $t$,

$K_t$ is the cumulative catch from population $N_0$ to the beginning of week $t$,

$f_t$ is the number of standard units of effort during week $t$,

$C_t/f_t$ is the catch per standard unit of effort during week $t$ from population $N_0$, and

TABLE 9.—*Recruits in the weekly catches of male crabs from the Neuse River, beginning 7 April 1958 and ending 9 November 1958*

| Trotline | | | Crab trawl | | | Shrimp trawl | | | Total | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Catch of males (pounds) | Ratio of recruits | Recruits (pounds) | Catch of males (pounds) | Ratio of recruits | Recruits (pounds) | Catch of males (pounds) | Ratio of recruits | Recruits (pounds) | Catch of males (pounds) | Recruits | Ratio of recruits |
| | | | 211 | 0.055 | 12 | | | | 211 | 12 | 0.057 |
| 123 | 0.025 | 3 | 5,365 | 0.055 | 295 | | | | 5,488 | 298 | 0.054 |
| 217 | 0.057 | 12 | 21,625 | 0.055 | 1,189 | | | | 21,842 | 1,201 | 0.055 |
| 590 | 0.066 | 39 | 13,097 | 0.069 | 904 | | | | 13,687 | 943 | 0.069 |
| 1,021 | 0.072 | 74 | 8,803 | 0.080 | 704 | | | | 9,824 | 778 | 0.079 |
| 7,402 | 0.072 | 533 | 28,976 | 0.080 | 2,318 | | | | 36,378 | 2,851 | 0.078 |
| 26,762 | 0.072 | 1,927 | 33,923 | 0.080 | 2,714 | | | | 60,685 | 4,641 | 0.076 |
| 26,113 | 0.086 | 2,246 | 29,319 | 0.076 | 2,228 | | | | 55,432 | 4,474 | 0.081 |
| 29,359 | 0.171 | 5,020 | 32,549 | 0.056 | 1,823 | 208 | 0.098 | 20 | 62,116 | 6,863 | 0.110 |
| 38,476 | 0.171 | 6,579 | 30,404 | 0.056 | 1,703 | 2,065 | 0.115 | 237 | 70,945 | 8,519 | 0.120 |
| 44,011 | 0.171 | 7,526 | 54,798 | 0.056 | 3,069 | 5,638 | 0.115 | 648 | 104,447 | 11,243 | 0.108 |
| 22,776 | 0.171 | 3,895 | 25,815 | 0.056 | 1,446 | 8,676 | 0.115 | 998 | 57,267 | 6,339 | 0.111 |
| 31,160 | 0.081 | 2,524 | 9,406 | 0.060 | 564 | 6,756 | 0.065 | 439 | 47,322 | 3,527 | 0.074 |
| 50,402 | 0.066 | 3,326 | 11,676 | 0.061 | 712 | 13,751 | 0.057 | 784 | 75,829 | 4,822 | 0.064 |
| 51,183 | 0.066 | 3,378 | 17,791 | 0.061 | 1,085 | 21,527 | 0.057 | 1,227 | 90,501 | 5,690 | 0.063 |
| 48,139 | 0.066 | 3,177 | 14,421 | 0.061 | 880 | 19,783 | 0.057 | 1,128 | 82,343 | 5,185 | 0.063 |
| 49,170 | 0.056 | 2,754 | 12,396 | 0.053 | 657 | 23,355 | 0.049 | 1,144 | 84,921 | 4,555 | 0.054 |
| 39,098 | 0.042 | 1,642 | 4,870 | 0.042 | 204 | 19,658 | 0.038 | 747 | 63,626 | 2,593 | 0.041 |
| 43,530 | 0.042 | 1,828 | 5,678 | 0.042 | 238 | 27,239 | 0.038 | 1,035 | 76,447 | 3,101 | 0.040 |
| 41,637 | 0.042 | 1,749 | 2,588 | 0.042 | 109 | 24,830 | 0.038 | 944 | 69,055 | 2,802 | 0.040 |
| 17,533 | 0.042 | 736 | 1,844 | 0.042 | 77 | 24,999 | 0.038 | 950 | 44,376 | 1,763 | 0.040 |
| 28,821 | 0.043 | 1,239 | 1,348 | 0.046 | 62 | 17,072 | 0.043 | 734 | 47,241 | 2,035 | 0.043 |
| 27,866 | 0.043 | 1,198 | 2,307 | 0.046 | 106 | 21,647 | 0.043 | 931 | 51,820 | 2,235 | 0.043 |
| 22,494 | 0.043 | 967 | 1,275 | 0.046 | 59 | 11,756 | 0.043 | 506 | 35,525 | 1,532 | 0.043 |
| 16,126 | 0.043 | 693 | 642 | 0.046 | 30 | 11,855 | 0.043 | 510 | 28,623 | 1,233 | 0.043 |
| 5,391 | 0.037 | 199 | | | | 333 | 0.045 | 15 | 5,724 | 214 | 0.037 |
| 4,012 | 0.035 | 140 | 9 | 0.046 | — | 1,220 | 0.046 | 56 | 5,241 | 196 | 0.037 |
| 6,005 | 0.035 | 210 | | | | 1,445 | 0.046 | 66 | 7,450 | 276 | 0.037 |
| | | | 166 | 0.046 | 8 | 382 | 0.046 | 18 | 548 | 26 | 0.047 |
| 1,467 | 0.037 | 54 | 467 | 0.046 | 21 | 1,450 | 0.045 | 65 | 3,384 | 140 | 0.041 |
| 157 | 0.012 | 2 | 604 | 0.026 | 16 | 518 | 0.025 | 13 | 1,279 | 31 | 0.024 |

$c$ is the fraction taken by one unit of effort from the population during any week $t$.

The method of arranging the data to estimate the population at the beginning of week 6 (12–18 May) is shown in Table 11. In column 2 are the estimated catches each week ($C_t$) from the male population present 12 May (from Table 10). In column 3 are the estimated standard units of effort each week ($f_t$) on the population of males. These were obtained by multiplying total standard units of effort each week by the proportion of males estimated to be in the weekly catches. Catches per standard unit effort each week ($C_t/f_t$) of males belonging to the population present 12 May are in column 4. In column 5 are the cumulative catches ($K_t$) up to a given week. The catch per standard fishing unit ($C_t/f_t$) versus cumulative catch ($K_t$) is plotted in Figure 2. Assuming a linear relationship between catch per standard unit of effort ($C_t/f_t$) and cumulative catch ($K_t$), then the equation $C_t/f_t = cN_0 - cK_t$, can be derived (Ricker, 1958). Estimates of the slope and the $C_t/f_t$-axis intercept give estimates of $c$ and $cN_0$, respectively. Estimates of $c$ and $cN_0$ for the data in Table 11 were calculated by the least squares method (Snedecor, 1956), and are 0.000561 and 185.379, respectively, from which an estimate of $N_0$ equal to 330,000 (pounds) is obtained. Therefore, the line that best describes the relationship between $C_t/f_t$ and $K_t$ is $C_t/f_t = 185.379 - 0.000561\ K_t$. The estimate of $N_0$ can also be obtained from Figure 2 by extrapolating the regression line to the $K_t$ axis. This is the same as putting $C_t/f_t$ equal to 0 in the above equation since, theoretically, the intercept on the $K_t$ axis is the point where the catch per unit effort ($C_t/f_t$) is zero and therefore the cumulative catch at this point represents the population, $N_0$.

Population estimates for male crabs (Table 12) at the beginning of each week up to the week beginning 4 August were calculated by treating the catch–effort data after any given time in the same way as the data were handled for deriving the 12 May abundance estimate. The number of weeks of data used to calculate the estimate is in parentheses alongside each population estimate. These numbers decline

TABLE 10.—*Estimates of the pounds of male crabs caught each week that were recruits during the week and during previous weeks, 12 May–6 July 1958*

| Week No. | Date | Estimated catch of males | Week recruited | Proportion of recruits | Catch of recruits | Residuals |
|---|---|---|---|---|---|---|
| 6 | 12–18 May | 36,378 | 6 | 0.078 | 2,837 | 33,541 |
| 7 | 19–25 May | 60,685 | 7 | 0.076 | 4,612 | 56,073 |
| | | | 6 | 0.156 | 8,747 | 47,326 |
| 8 | 26 May–1 June | 55,432 | 8 | 0.081 | 4,490 | 50,942 |
| | | | 7 | 0.152 | 7,743 | 43,199 |
| | | | 6 | 0.156 | 6,739 | 36,460 |
| 9 | 2–8 June | 62,116 | 9 | 0.110 | 6,833 | 55,283 |
| | | | 8 | 0.162 | 8,956 | 46,327 |
| | | | 7 | 0.152 | 7,042 | 39,285 |
| | | | 6 | 0.156 | 6,128 | 33,157 |
| 10 | 9–15 June | 70,945 | 10 | 0.120 | 8,513 | 62,432 |
| | | | 9 | 0.220 | 13,735 | 48,697 |
| | | | 8 | 0.162 | 7,889 | 40,808 |
| | | | 7 | 0.152 | 6,203 | 34,605 |
| | | | 6 | 0.156 | 5,398 | 29,207 |
| 11 | 16–22 June | 104,447 | 11 | 0.108 | 11,280 | 93,167 |
| | | | 10 | 0.240 | 22,360 | 70,807 |
| | | | 9 | 0.220 | 15,578 | 55,229 |
| | | | 8 | 0.162 | 8,947 | 46,282 |
| | | | 7 | 0.152 | 7,035 | 39,247 |
| | | | 6 | 0.156 | 6,122 | 33,125 |
| 12 | 23–29 June | 57,267 | 12 | 0.111 | 6,357 | 50,910 |
| | | | 11 | 0.216 | 10,996 | 39,914 |
| | | | 10 | 0.240 | 9,579 | 30,335 |
| | | | 9 | 0.220 | 6,674 | 23,661 |
| | | | 8 | 0.162 | 3,833 | 19,828 |
| | | | 7 | 0.152 | 3,014 | 16,814 |
| | | | 6 | 0.156 | 2,623 | 14,191 |
| 13 | 30 June–6 July | 47,322 | 13 | 0.074 | 3,502 | 43,820 |
| | | | 12 | 0.222 | 9,728 | 34,092 |
| | | | 11 | 0.216 | 7,364 | 26,728 |
| | | | 10 | 0.240 | 6,415 | 20,313 |
| | | | 9 | 0.220 | 4,469 | 15,844 |
| | | | 8 | 0.162 | 2,567 | 13,277 |
| | | | 7 | 0.152 | 2,018 | 11,259 |
| | | | 6 | 0.156 | 1,756 | 9,503 |

as the fishing season continues because the catch–effort data for the weeks at the end of the season reflected changes in catchability due to weather rather than changes in abundance with constant catchability. Also in Table 12 are total population estimates obtained by dividing the estimates of male abundance by the ratio of commercial-size males to the total catch during the following week.

Confidence limits for the population of male crabs 7 July (week 14, $\hat{N}_0 = 561{,}000$ pounds) were obtained by finding the roots of the quadratic equation, $N^2(\hat{k}^2 - t_\alpha{}^2 s^2 c_{22}) - 2N[\hat{k}(\widehat{kN}) - t_\alpha{}^2 s^2 c_{12}] + [(\widehat{kN})^2 - t_\alpha{}^2 s^2 c_{11}] = 0$ (DeLury, 1951). In terms of the notation presented earlier, and letting $m$ equal the number of observations, then:

$$\hat{k} = \hat{c}, \qquad \widehat{kN} = \widehat{cN_0},$$

$$c_{11} = \Sigma K_t{}^2/m[\Sigma K_t{}^2 - (\Sigma K_t)^2/m],$$

$$c_{12} = \Sigma K_t/m[\Sigma K_t{}^2 - (\Sigma K_t)^2/m], \quad \text{and}$$

$$c_{22} = 1/[\Sigma K_t{}^2 - (\Sigma K_t)^2/m].$$

The variance about the regression line is set equal to $s^2$, and ". . . $t_\alpha$ is the tabulated $t$-value at the 1-$\alpha$ confidence level with $m$-2 degrees of freeedom. . ." (DeLury, 1951).

The 95% confidence limits for the population estimate of 561,000 pounds of male crabs on 7 July were 514,000 and 624,000 pounds. Dividing these limits by 0.779, the ratio of males estimated to have been caught during the week 7–13 July (75,829 pounds, Table 7) to the total catch during the week (97,375 pounds, week 14, Table 1), estimates of the confidence limits (660,000 and 801,000 pounds) for the total population (716,000 pounds) on 7 July were obtained.

The confidence limits derived for the total population 7 July are minimal limits mainly because three factors have not been taken into account. These factors are as follows:

Table 11.—*Data used in the Leslie method for obtaining an estimate of the population of commercial-size male crabs on 12 May 1958*

| Week | Catch of male crabs ($C_t$) (pounds) | Standard fishing units ($f_t$) | Catch per standard fishing unit ($C_t/f_t$) (pounds) | Cumulative catch ($K_t$) (thousands of pounds) |
|---|---|---|---|---|
| 12 May–18 May | 33,541 | 194 | 172.9 | 0.0 |
| 19 May–25 May | 47,326 | 248 | 190.8 | 33.5 |
| 26 May–1 June | 36,460 | 243 | 150.0 | 80.9 |
| 2 June–8 June | 33,157 | 301 | 110.2 | 117.3 |
| 9 June–15 June | 29,207 | 357 | 81.8 | 150.5 |
| 16 June–22 June | 33,125 | 352 | 94.1 | 179.7 |
| 23 June–29 June | 14,191 | 269 | 52.8 | 212.8 |
| 30 June–6 July | 9,503 | 244 | 38.9 | 227.0 |
| 7 July–13 July | 13,115 | 256 | 51.2 | 236.5 |
| 14 July–20 July | 13,663 | 248 | 55.1 | 249.6 |
| 21 July–27 July | 10,865 | 234 | 46.4 | 263.3 |
| 28 July–3 August | 9,887 | 227 | 43.6 | 274.2 |

Table 12.—*Weekly Neuse River crab catch and estimates of population in thousands of pounds, 12 May–4 August 1958*

[estimates of population are for the beginning of the week]

| Week | Catch | | Population estimates | |
|---|---|---|---|---|
| | Males | Total | Males | Total |
| 6 | 36 | 43 | 330 (12)[1] | 394 |
| 7 | 61 | 73 | 346 (12) | 414 |
| 8 | 55 | 68 | 361 (12) | 446 |
| 9 | 62 | 79 | 396 (12) | 504 |
| 10 | 71 | 91 | 446 (12) | 572 |
| 11 | 104 | 132 | 477 (12) | 605 |
| 12 | 57 | 73 | 554 (12) | 710 |
| 13 | 47 | 60 | 596 (12) | 761 |
| 14 | 76 | 97 | 561 (12) | 716 |
| 15 | 90 | 118 | 530 (11) | 695 |
| 16 | 82 | 108 | 509 (10) | 670 |
| 17 | 85 | 112 | 492 (9) | 648 |

[1] See text for explanation.

1) the variance of the ratio (0.779) used to convert male population limits to total population limits.

2) the variance of the male recruitment rates for the weeks after 7 July. These rates were used to eliminate recruits from the catches after this date. This was necessary so that the portions of the remaining weekly catches would be from the "closed" (DeLury, 1951) population on 7 July.

3) the distribution of the $C_t/f_t$ values possibly departing somewhat from normality.

Confidence limits were determined for the population on 7 July rather than another date because, in later sections of this paper, estimates are obtained for this same date by other methods.

### *Alternate method using catch, effort, and recruitment data*

Another method of estimating population size employing catch and effort data, and estimates of recruitment, was suggested by Dr. D. G. Chapman of the Department of Mathematics at the University of Washington. The derivation of the method and its application to the crab data are presented.

Let $C_t/f_t$ be the catch per standard unit effort in week $t$. Under the assumption that the units of effort do not compete with each other (DeLury, 1947),

$$C_t/f_t = c\bar{N}_t\,, \qquad (1)$$

where $c$ is the proportion of the population captured during week $t$ by one unit of effort, and $\bar{N}_t$ is the average population size during the week. If $N_t$ equals the population size at the end of week $t$ and $N_{t-1}$ the population size just previous to week $t$, then the approximate average population size ($\bar{N}_t$) during week $t$ can be described as $(N_{t-1} + N_t)/2$ and equation (1) can be written

$$C_t/f_t = c(N_{t-1} + N_t)/2\,. \qquad (2)$$

Let the recruits ($R_t$) to the population during week $t$ be expressed as

$$R_t = r_t(N_{t-1} + N_t)/2\,, \qquad (3)$$

where $r_t$ is a certain fraction of the average population in week $t$. However, no functional relationship of recruitment rate ($r_t$) with population size is implied. Now considering the population at the end of week $t$,

$$N_t = N_{t-1} - C_t + R_t\,, \qquad (4)$$

where $C_t$ is the catch during week $t$, and substituting equation (3) for $R_t$,

$$N_t = N_{t-1}[(2 + r_t)/(2 - r_t)] - C_t/(2 - r_t). \quad (5)$$

Substituting equation (5) for $N_t$ in equation (2)

$$C_t/f_t = (c/2)\{N_{t-1}[(2 + r_t)/(2 - r_t)] \\ - 2[C_t/(2 - r_t)] + N_{t-1}\} \quad (6)$$

or

$$C_t/f_t = c\{N_{t-1}[2/(2 - r_t)] - C_t/(2 - r_t)\}. \quad (7)$$

Choosing some starting point, say $t = 0$, then the catch per standard unit of effort during the first week equals

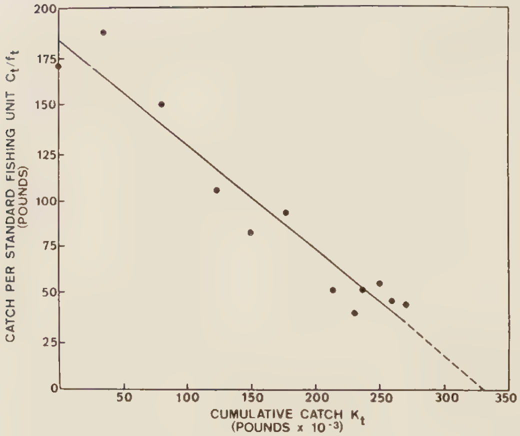

FIGURE 2.—The estimated catch per unit of effort of male crabs versus the cumulative catch from the male population on 12 May 1958.

$$C_1/f_1 = c\{N_0[2/(2-r_1)] - C_1/(2-r_1)\} \quad (8)$$

or

$$[(2-r_1)/2]C_1/f_1 = cN_0 - cC_1/2. \quad (9)$$

During the second week,

$$C_2/f_2 = c\{N_1[2/(2-r_2)] - C_2/(2-r_2)\}, \quad (10)$$

and from equation (5), letting $N_1 = N_t$,

$$C_2/f_2 = c[\![ [2/(2-r_2)] \times \{[N_0(2+r_1)/(2-r_1)] - 2C_1/(2-r_1)\} - C_2/(2-r_2)]\!] \quad (11)$$

or

$$[(2-r_1)(2-r_2)/2(2+r_1)]C_2/f_2 = cN_0 - c\{2[C_1/(2+r_1)] + (2-r_1)C_2/2(2+r_1)\}. \quad (12)$$

For any week, $t$, after the second week

$$[(2-r_t)\ldots(2-r_1)/2(2+r_t)\ldots(2+r_1)] \times C_t/f_t = cN_0 - c\{2[C_1/(2+r_1)] + 2[C_2(2-r_1)/(2+r_1)(2+r_2)] + \ldots + 2[C_{t-1}(2-r_{t-2})\ldots(2-r_1)]/[(2+r_{t-1})\ldots(2+r_1)] + C_t(2-r_{t-1})\ldots(2-r_1)/[2(2+r_{t-1})\ldots(2+r_1)]\}. \quad (13)$$

If the recruitment rate, catch, and standard units of effort for each week are known, a set of equations similar to (9) and (12) can be calculated from the general equation (13). Letting $Y_t$ equal the left-hand sides of these equations and $X_t$ equal the coefficients of the minus $c$ terms, the unknown parameters $cN_0$ and $c$ can be estimated by the usual regression methods.

Starting at 12 May, weekly catch and effort data and the estimates of the weekly recruitment rates were substituted in equation (13) to obtain the $Y_t$ and $X_t$ values shown in Table 13 and Figure 3. Considering $Y_t = cN_0 - c\,X_t$, and treating $Y_t$ as a dependent normally distributed variable with equal variances for each value of $X$ the independent variable, "least squares" estimates were calculated for the parameters $cN_0$ and $c$. The estimate of $c$, the catchability, was 0.000442 and of $N_0$, the population on 12 May, was 448,549 pounds. The regression of $Y_t$ on $X_t$ was highly significant.

The weekly recruitment rates presented in Table 13 were calculated from the daily rates in Table 4. During the week of 12–18 May, for example, the recruitment rate shown in Table 13 (0.147) was obtained by summing the daily rate of 2.1% (1–15 May, Table 4) for 12, 13, 14, and 15 May; and the daily rate, also 2.1% (16–31 May, Table 4), for the remainder of the week, 16, 17, and 18 May.

These recruitment rates (Table 13) are estimates of the total pounds of crabs recruited during the week to the commercial-size population at the beginning of the week. In the derivation of the above method of estimating population size, especially in equation (3), it would have been more correct to use instantaneous weekly recruitment rates. However, the weekly total recruitment rates were not converted to the slightly lower instantaneous weekly rates because the use of the higher total recruitment rates compensates in a rough manner for the unmeasured small amount of growth in weight (as contrasted to the increase in weight due to recruitment) of the commercial-size crab population.

Estimates of the population at the end of the week (Table 14) were obtained by successive substitution into equation (5) of the catch and recruitment rate estimates for the week (Table 13), as well as the population estimate at the beginning of the week. As an example, the population estimate at the

TABLE 13.—*Weekly crab catch per standard unit of effort, and recruitment rate estimates for Neuse River, 12 May to 28 September 1958. Cumulative products of $(2-r_t)$ and $(2+r_t)$ used in equation (13) to determine $Y_t$ and $X_t$ values, are also shown*

| Week | Catch per standard unit effort $(C_t/f_t)$ (pounds) | Recruitment rate $(r_t)$ | Cumulative product of $(2-r_t)$ | Cumulative product of $(2+r_t)$ | $Y_t$ | $X_t$ |
|---|---|---|---|---|---|---|
| 12–18 May | 186.0 | 0.147 | 1.8530 | 2.1470 | 172.33 | 2,167.00 |
| 19–25 May | 244.5 | 0.147 | 3.4336 | 4.6096 | 195.51 | 72,032.12 |
| 26 May–1 June | 226.7 | 0.161 | 6.3144 | 9.9613 | 155.27 | 124,512.05 |
| 2–8 June | 203.9 | 0.245 | 11.0818 | 22.3631 | 113.42 | 170,864.93 |
| 9–15 June | 196.4 | 0.245 | 19.4486 | 50.2052 | 85.40 | 212,897.56 |
| 16–22 June | 292.5 | 0.245 | 34.1323 | 112.7107 | 99.43 | 256,123.54 |
| 23–29 June | 210.0 | 0.245 | 59.9022 | 253.0355 | 55.80 | 287,210.05 |
| 30 June–6 July | 194.5 | 0.175 | 109.3215 | 550.3522 | 42.02 | 302,997.27 |
| 7–13 July | 293.3 | 0.161 | 201.0422 | 1,189.3111 | 53.57 | 318,657.09 |
| 14–20 July | 370.0 | 0.126 | 376.7531 | 2,528.4754 | 58.60 | 336,895.08 |
| 21–27 July | 350.6 | 0.112 | 711.3098 | 5,340.1400 | 49.32 | 353,735.97 |
| 28 July–3 Aug. | 373.7 | 0.112 | 1,342.9529 | 11,278.3757 | 46.99 | 368,371.92 |
| 4–10 Aug. | 266.1 | 0.112 | 2,535.4951 | 23,819.9295 | 29.91 | 380,038.30 |
| 11–17 Aug. | 274.2 | 0.105 | 4,804.7632 | 50,140.9516 | 27.66 | 389,870.93 |
| 18–24 Aug. | 283.7 | 0.084 | 9,205.9263 | 104,493.7431 | 26.04 | 399,069.71 |
| 25–31 Aug. | 258.8 | 0.084 | 17,638.5548 | 217,764.9606 | 21.84 | 405,681.19 |
| 1–7 Sept. | 238.4 | 0.175 | 32,190.3625 | 473,638.7893 | 17.62 | 410,620.66 |
| 8–14 Sept. | 246.6 | 0.175 | 58,747.4116 | 1,030,164.3667 | 15.29 | 415,131,36 |
| 15–21 Sept. | 202.3 | 0.091 | 112,148.8087 | 2,154,073.6908 | 11.01 | 448,464.97 |
| 22–28 Sept. | 170.2 | 0.077 | 215,662.1591 | 4,474,011.0558 | 8.52 | 420,692.93 |

end of week 12–18 May was $(2+0.147)$ $(448{,}549)$ / $(2-0.147)$ − $2(43{,}342)$ / $(2-0.147)$, or 472,936 pounds. This figure was then used as the value of $N_{t-1}$ in equation (5) to calculate the population estimate at the end of week 19–25 May.

### *Parker method*

This method involves the plot of the transformed daily ratios of the catch of marked fish to the total daily catch of fish (from a population in which recruitment is occurring) against the number of days after marking. If the transformed ratios are plotted on the $Y$-axis, and the number of days after marking on the $X$-axis, then an estimate of the initial population can be derived from the intercept on the $Y$-axis (Parker, 1955).

In using this method to estimate the population of fish of the genus *Lepomis* in a Wisconsin lake, Parker worked with fixed fishing gear and assumed that (1) the catchability of tagged and untagged fish was the same during each day, (2) the tagged fish were randomly dispersed, and (3) the absolute rate of recruitment was constant during the fishing period after tagging. It is not clear whether Parker assumed that the number of recruits or the rate of recruitment to the catchable population was constant. For the present assumptions 1 and 2 will be considered fulfilled. Discussion of all the assumptions and departures from them will be made in the following paragraphs and in a later section of the paper.

Parker (1955) did not give a detailed account of the method he used, and below is presented a possible theoretical basis for the method. This was developed from discussions with Dr. Gerald Paulik of the College of Fisheries, University of Washington, and from reference to an article on the subject of population estimates by Nose (1961). Assuming:

$N_0$ equals the initial population at time, $t=0$,
$T_0$ is the number of marked individuals available at $t=0$,
$Z$ equals the constant instantaneous daily recruitment rate to the catchable population,
$r$ equals the constant daily recruitment rate and $r=e^Z$,
$F_t$ equals the instantaneous rate of fishing during day $t$,
$M_t$ equals the daily instantaneous rate of natural mortality,
$s_t$ equals the fraction surviving at the end of day $t$,
$u_t$ equals the fraction (exploitation rate) of the marked members in the population present at the beginning of day $t$ that are caught during day $t$,
$u_t'$ equals the exploitation rate on the

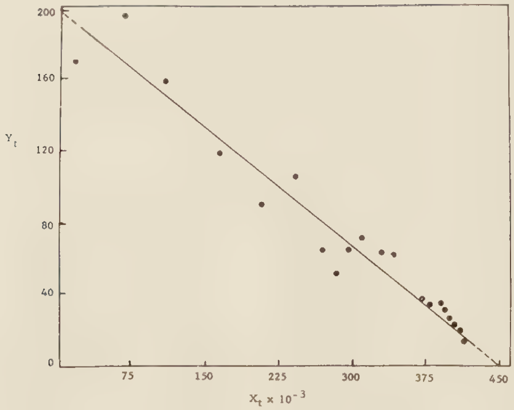

FIGURE 3.—$X_t$ and $Y_t$ values for 20 weeks beginning 12 May 1958. The $X_t$ and $Y_t$ values were obtained from equation (13).

unmarked members in the population during day $t$ when recruitment is occurring, and

$P_t$ equals the ratio of the catch of marked ($R_t$) to unmarked ($C_t$) members of the population in day $t$.

The number of marked fish recaptured during the first day after release equals $u_1T_0$ and the catch of unmarked fish equals $u_1'N_0$. During the second day, the marked and unmarked fish recaptured equal $u_2T_0s_1$ and $u_2'N_0s_1r$, respectively. The ratio of marked to unmarked fish caught during the second day ($P_2$) is $u_2T_0s_1 : u_2N_0s_1r$, and during any day $t$,

$$P_t = u_tT_0s_0s_1 \ldots s_{t-1}/u_t'N_0r^{t-1}s_0s_1 \ldots \ldots s_{t-1}\,, \tag{14}$$

where $s_0$ equals one. Assuming that the survival rate each day is the same for the marked and unmarked fish, then equation (14) reduces to

$$P_t = u_tT_0/u_t'N_0r^{t-1}. \tag{15}$$

The exploitation rate on the marked fish during any day $t$ ($u_t$) can be expressed as $u_t = F_t[1-\exp-(F_t+m_t)](F_t+M_t)^{-1}$, the unmarked fish ($u_t'$) as $F_t[1-\exp-(F_t+M_t-Z)](F_t+M_t-Z)^{-1}$. Dividing $u_t$ by $u_t'$, then

$$\frac{[1-\exp-(F_t+M_t)](F_t+M_t)^{-1}}{[1-\exp-(F_t+M_t-Z)](F_t+M_t-Z)^{-1}}$$

can be approximated by

$$[1-\tfrac{1}{2}(F_t+M_t)][1-\tfrac{1}{2}(F_t+M_t-Z)]^{-1}. \tag{16}$$

This in turn can be approximated by

$$\frac{\exp-\tfrac{1}{2}(F_t+M_t)}{\exp-\tfrac{1}{2}(F_t+M_t-Z)}. \tag{17}$$

Simplifying this fraction (17), $u_t/u_t'$ is shown to equal approximately $1/\exp \tfrac{1}{2}(Z)$ or, in terms of the daily recruitment rate, $1/r^{1/2}$.

Referring to equation (15), and letting $1/r^{1/2}$ replace $u_t/u_t'$, then the estimate of the ratio of marked to unmarked fish on any day $t$, equals

$$E(p_t) = T_0/N_0r^{(2t-1)/2}. \tag{18}$$

Taking the natural logarithm of equation (18) and letting $Y_t$ equal the natural logarithm of the ratio of the catch of marked to unmarked fish on day $t$, then

$$Y_t = [\ln(T_0/N_0) + \tfrac{1}{2}\ln r] + (-\ln r)t. \tag{19}$$

Equation (19) suggests a straight line relationship might exist between the logarithm of $P_t$ and the days after release ($t$). Knowing $T_0$ and estimating $r$ from the slope of the straight line, an estimate of the initial population $N_0$, can be obtained from the $Y$-axis intercept.

If one assumes, as Parker (1955) did, that the logarithm of the $P_t$ values will give an approximate linear relationship with time, and that each of the values are from approximately normally distributed populations with

TABLE 14.—*Estimates of the population of commercial-size crabs obtained by successive substitution into equation,* $N_t = [(2+r_t)(N_{t-1})/(2-r_t)] - 2C_t/(2-r_t)$

[estimates of population are for the end of each week]

| Week | Population estimate (pounds) |
|---|---|
| 5–11 May | 448,549 |
| 12–18 May | 472,936 |
| 19–25 May | 468,792 |
| 26 May–1 June | 477,415 |
| 2–8 June | 521,023 |
| 9–15 June | 562,855 |
| 16–22 June | 569,319 |
| 23–29 June | 644,993 |
| 30 June–6 July | 702,612 |
| 7–13 July | 719,736 |
| 14–20 July | 703,287 |
| 21–27 July | 672,703 |
| 28 July–3 August | 633,745 |
| 4–10 August | 620,128 |
| 11–17 August | 582,345 |
| 18–24 August | 538,336 |
| 25–31 August | 523,940 |
| 1–7 September | 555,432 |
| 8–14 September | 585,476 |
| 15–21 September | 591,919 |
| 22–28 September | 599,324 |

TABLE 15.—*Data used in Parker's method to estimate the crab population in the Neuse River on 4 July 1958*

| Date | Recoveries ($R_t$) (number) | Catch ($C_t$) (thousands of pounds) | Logarithm of $R_t/C_t$ ($Y_t$) | Days after end of marking ($X_t$) |
|---|---|---|---|---|
| 7 July | 13 | 21.8 | −0.54696 | 4 |
| 8 July | 10 | 16.5 | −0.50077 | 5 |
| 9 July | 7 | 16.0 | −0.82668 | 6 |
| 10 July | 7 | 27.5 | −1.36828 | 7 |
| 11 July | 6 | 15.0 | −0.91629 | 8 |
| 14 July | 3 | 32.0 | −2.36713 | 11 |
| 15 July | 1 | 22.0 | −3.09104 | 12 |
| 16 July | 6 | 22.3 | −1.31283 | 13 |
| 17 July | 2 | 23.4 | −2.45959 | 14 |
| 18 July | 3 | 18.0 | −1.79176 | 15 |
| 21 July | 3 | 31.4 | −2.34820 | 18 |
| 22 July | 1 | 16.6 | −2.80940 | 19 |
| 23 July | 3 | 18.6 | −1.82455 | 20 |
| 24 July | 1 | 22.7 | −3.12236 | 21 |
| 25 July | 2 | 17.8 | −2.18605 | 22 |
| 28 July | 3 | 34.6 | −2.44524 | 25 |
| 29 July | 3 | 31.7 | −2.35771 | 26 |
| 30 July | 1 | 18.4 | −2.91235 | 27 |

equal variances, then least squares estimates of the slope and $Y$-axis intercept are the best estimates of these parameters (Snedecor, 1956).

The estimate of the crab population on 4 July 1958, was obtained using Parker's method. During the week preceding 4 July, 384 tagged crabs of both sexes were released, 227 near Goose Creek and 157 near Oriental. Sixteen of these crabs recovered during the week preceding 4 July and seven recovered after 4 July by noncommercial fishing gears were considered not available to the commercial fishery during the period from 7 July to 30 July. This left 361 tagged crabs available to the commercial fishery. Molting by tagged male crabs is discussed in a later section of this paper. However, if near the end of the recovery period tagged males molted, recruitment rate estimates would show greater increases than those for population size. The increase in the estimates would be due to change in weight of the population from growth of commercial-size male crabs. In Table 15 are the recoveries, $R_t$, made each fishing day beginning 7 July and ending 30 July. The catches each day, $C_t$, the natural logarithms of the $P_t$ or $R_t/C_t$ values, and the number of days after 3 July (the last day of tagging prior to 4 July) are also in Table 15. The equation of the best fitting linear regression line (Figure 4), considering the logarithms of $R_t/C_t$ as $Y_t$ values and days after 3 July as $X_t$ values, is $\hat{Y}_t = -0.64996 - 0.086036\ X_t$. The slope of this regression line was highly significant. From the value of the $Y$-axis intercept, −0.64996, one-half the slope (0.086036/2) was subtracted (see equation 19). Taking the antilogarithm of the remainder and multiplying by $10^3$, an estimate was obtained of the initial ratio of tagged to untagged crabs ($T_0/N_0$) on 4 July. Dividing the number of marked crabs available 4 July (361) by this estimate of $T_0/N_0$, the population estimate of 722,000 pounds of crabs for 4 July was obtained.

An estimate of the error in the transformed $R_t/C_t$ value when $t = 0$ was calculated (Ricker, 1958). Using the estimate of error, 95% confidence limits for the population on 4 July were 516,000 and 1,009,000 pounds.

The use of the ratios of the numbers of marked crabs to pounds of unmarked crabs caught each day, rather than pounds of marked to unmarked crabs, did not affect the estimate of population as the tagged crabs at the time of release were considered representative of the commercial crab population 5 inches or more in width. Also, the ratio of commercial-size crabs 4.5–5 inches wide to

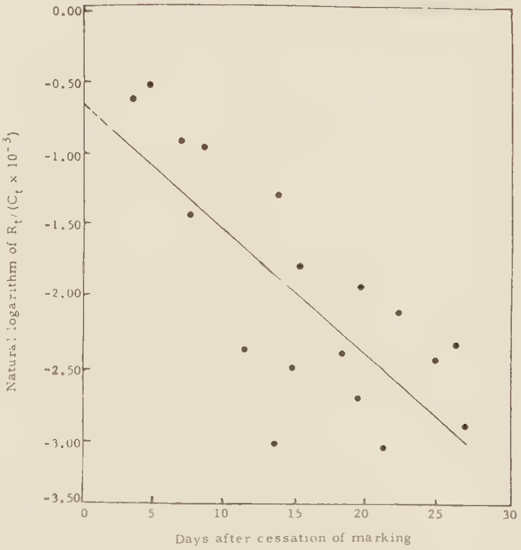

FIGURE 4.—The natural logarithm of the daily recoveries ($R_t$) divided by the daily catch ($C_t \times 10^{-3}$) for the tagged crabs released in the week prior to 4 July 1958.

crabs greater than 5 inches was assumed to be constant during the period from 4 July to 30 July.

Estimates of the population at the beginning of the weeks of 23 June and 21 July were calculated by the Parker method from recoveries of tagged crabs released in the weeks immediately prior to these dates. The estimates of the population were 657,000 and 789,000 pounds, respectively, for these dates.

In a later paper, Parker (1963) assumes when taking point samples that the expected numbers of marked individuals recaptured will follow a Poisson distribution. Parker then presented a method of estimating three population parameters, $N_0$, $i$ $(= F + M)$, and $r$ (in numbers), when minimizing the variance of differences between the expected and observed numbers of marked fish recaptured. Because some of the important assumptions necessary to the model outlined by Parker (1963) for estimating the population parameters were not satisfied by the Neuse River crab population, this method (Parker, 1963) was not used in this study.

### CRABS AVAILABLE TO THE FISHERY

An estimate of the commercial-size crabs available to the fishery in 1958 was obtained by adding the total catch to the estimated population at the end of the fishing season. It was assumed that natural mortality and predation upon commercial-size crabs during the fishing season were negligible (see Discussion) and that 44% of the female recruits emigrated and escaped the fishery during the fishing season.

The latest date during the fishing season for which population estimates are available, calculated by all three methods, is 21 July. The Leslie method gave an estimate of 670,000 pounds (Table 12); the Alternate method, using catch, effort, and recruitment data, 703,000 pounds (Table 14); and the Parker method, 789,000 pounds. Because no evidence suggested that one particular method gave more accurate estimates, the average of these estimates, 721,000 was considered the best estimate of the population on 21 July.

In order to obtain an estimate of the population at the end of the fishing season, the following procedure was used:

The estimate of the population 21 July was split into estimates of the populations of male and female crabs on this date (552,000 and 169,000 pounds). This was accomplished by multiplying the total population by the ratio of males (0.765) estimated to be in the catch during the week of 21–27 July (see Tables 1 and 7). The male population estimate of 552,000 pounds was then multiplied by 2 × 0.063 (see Table 9, last column), the estimated male recruitment rate for the week, giving an estimated 70,000 pounds of male recruits during the week. The catch of male crabs during the week was estimated as 82,000 pounds (Table 9). Adding the recruits and subtracting the catch from 552,000 pounds, an estimate of 540,000 pounds was obtained for the population of male crabs at the beginning of the week of 28 July.

Estimates of the male crab population at the beginning of each week up to 22 September were obtained by continuing the above process. The estimate for 22 September was 378,000 pounds of male crabs. Estimates of the male crab population for later dates were not calculated because estimates of the recruitment rate and sex ratio, obtained from the catch samples were not available after the week of 22–28 September. Also, during October and November the number of recruits to the population was negligible, as suggested by the almost complete absence of soft or peeler crabs in the fishermen's catches. Using the male crab population estimate for 22 September, a total population estimate of 508,000 pounds was calculated for this date by dividing the male crab population by 0.744 (the estimated ratio of male crabs in the total catch during the week of 22–28 September).

In the Neuse River from 7 April to 10 November, 1958, 2.140 million pounds of crabs were estimated to have been available to the fishery. This figure is the estimated population on 22 September, 0.508 million pounds, and the total catch of the three major types of gear up to 22 September, 1.632 million pounds. It was assumed that recruitment from 22 September to 9 November was negligible and that for the entire season a constant percentage of the female crabs recruitable to the population emigrated to Pamlico Sound precluding availability to capture in the river.

## DISCUSSION

### *Influence of weather and competition between units of gear on the catch per unit of effort*

For almost 2 weeks in the middle of the fishing season (22 June to 3 July) northeast winds from 5 to 11 knots reduced the amount of successful fishing time each day and, as a result, the daily catch per unit of effort. Of the three major fishing gears, trotlines would be most affected by weather. However, the multiple regression of trotline catch per unit of effort in relation to average wind speed and average wind direction each day during the fishing season was not significant. Therefore, weather was considered not to have reduced the usefulness of catch per unit of effort as a measure of relative abundance, except at the very beginning and end of the fishing season and from 22 June to 3 July.

If an increase or decrease in the number of units of effort is followed by an immediate decrease or increase in catch per unit of effort, competition between fishing units may be indicated. These relationships were not found during the season (Table 1), however, and gear competition as it affected catchability was not considered present in the fishery.

### *Ratio of soft crabs to hard crabs*

The numbers of soft crabs and the pounds of hard crabs caught by trawl fishermen in 1958 were obtained from the records of crab dealers. After converting the numbers of soft crabs to estimated weight of soft crabs,[2] ratios of soft to hard crabs each day were calculated. These ratios of soft to hard crabs were estimates of the daily recruitment rates. They agreed with the recruitment rates calculated from the catch samples (Table 4).

### *Natural mortality and predation*

Continuous inspection of catches made by trawls during the fishing season revealed dead crabs only in the early spring. The state of deterioration of these dead crabs suggested they died during the winter. The natural mortality of commercial-size crabs available during the fishing season, therefore, was considered negligible. There was no reason to believe that natural mortality of tagged crabs differed from that of the untagged crabs. Of the releases in the Neuse River and Pamlico Sound, there were no tag returns by trawl fishermen or others in which tags were reported attached to dead crabs.

Fish predation upon precommercial- and commercial-size crabs in the Neuse River was not studied. Studies by Roelofs (1950, 1954) in Pamlico Sound and tributary waters suggested that fish predation, especially upon the larger size crabs in these waters, was negligible. Roelofs (1954) reported that the croaker, *Micropogon undulatus* (Linnaeus), and the spot, *Leiostomus xanthurus* Lacépède, "comprise about 90% of the benthonic fish population in Pamlico Sound and tributary waters." Of the more than 200 croaker and spot stomachs he examined, decapods were found in about 4%. Most of these decapods were not blue crabs but were commercially unimportant shrimps and prawns of the suborder Macrura.

### *Loss of tags*

Mature females do not molt. There is the possibility, however, that some of the smaller tagged males (5 to 6 inches) molted and lost their tags in the 2-month periods after release, when most recoveries were made. For the tagged males released into the Neuse River, an analysis of variance test of the difference between the mean width of tagged male crabs recovered and the mean of those not recovered was not significant (5% level). It was concluded, therefore, that smaller tagged male crabs did not molt at a faster rate than the larger tagged male crabs. This conclusion does not eliminate the possibility of both size groups molting at the same rate. However, since almost all the shed carapaces caught by trawl fishermen were less than 5 inches in width, and since no recoveries of tags attached to shed carapaces were reported by these fishermen, it was concluded that tag loss due to molting was negligible.

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[2] A factor of 3.47 soft crabs per pound was used to convert numbers to pounds of soft crabs. Unpublished data, U. S. Bureau of Commercial Fisheries, Biological Laboratory, Beaufort, N. C.

Since tag loss by molting and from natural mortality and predation are considered negligible or insignificant, the reasons for the low tag return percentages from the releases in Pamlico Sound and the Neuse River must be connected with the fishery in these areas. In Pamlico Sound the low return percentage (19%, Table 2) is attributed to the intermittent fishery. In the Neuse River, however, the fishery took 81% of the estimated 2.1 million pounds of available crabs, but only approximately 20% of the tagged females and 34% of the males (Table 2). The low percentage return from females is attributed mainly to their movement out of the river into Pamlico Sound. For the tagged males released in the river the percentage return from those released during the first half of the crabbing season (40%) to the returns from releases during the latter half, (28%) suggests that equal amounts of fishing effort on the early and late releases would have resulted in a total return of at least 40%. In the following section of this paper an explanation is given for this still low percentage of tag returns.

### *Selectivity and availability*

If the three major types of fishing gear were selective for any particular size class of crabs, this selectivity could have caused erroneous estimates of recruitment rate calculated from catch samples. However, the frequency distribution of the crabs in the catch samples suggested nonselectivity for particular size groups of crabs.

The availability of the total crab population to fishing in the Neuse River was indicated by the relative number of daily returns from tagged crabs, and by the estimates of the average daily recruitment rates calculated in the Parker method. Returns, from the releases during the week previous to 7 July (Table 15), and the estimate of the average daily recruitment rate obtained from the relation of the tagged to untagged crabs in the daily catch after 4 July (Parker method) will be used to explain this statement.

It is assumed that the rate of natural mortality for the tagged crabs released in the few days prior to 4 July was not different from the rate for untagged crabs, that the tagged crabs were randomly distributed or that fishing effort was uniform on all stocks in the river population, and under these assumptions, and with approximately equal catches during each week after tagging, the proportionate weekly reduction in the number of tagged crabs recovered should reflect the approximate weekly recruitment rate. In other words, if the recruits during each of 2 weeks are approximately 25% of the population at the beginning of the week, and the catches during both weeks are equal, then the number of tags recovered the second week should be approximately 25% less.

During the 3 weeks after 4 July, the catch averaged 108,000 pounds per week (Table 1) and the catches per standard unit of effort were 293, 370, and 351 pounds (Table 1), suggesting an increase in population of at most 25%. However, the decreasing tag returns (43, 15, 10) suggested that the population increased about 55% each week. Only part of this decrease in the number of returns each week can be attributed to recruitment. Based on knowledge of the fishery and tag return locations, the major causes of this apparent decrease were the concentration of the fishery and the tagged crabs in the release areas during the first week, and the reduced availability of slower dispersing tagged crabs relative to the fishing effort in the second and third weeks.

The estimate (0.086) of the average instantaneous daily recruitment rate, $Z$ (see Parker method, equation 19 where $Z = \ln r$), was the regression slope relating the logarithm of the catch of tagged and untagged crabs to the days after 4 July. On the basis of the recruitment rates estimated from the catch samples (Table 4) and the catch per standard unit of effort for the 3 weeks after 4 July, an actual $Z$ value of 0.086 was extremely unlikely. Based on the estimated increase in population size and on catch per unit of effort, the actual average daily instantaneous recruitment rate was, at most, 0.05. The difference between 0.05 and the estimated 0.086 can be considered a measure of the increase in the availability of untagged crabs (movement of the fishing fleet from the release areas) relative to the decreased availability of tagged crabs.

## SUMMARY AND CONCLUSIONS

1. During 1958 trotlines, crab trawls, and shrimp trawls caught 1.7 million pounds of blue crabs in the Neuse River, North Carolina. Estimates of the population of crabs in the river were calculated from the catch–effort, catch–sampling, and tag-recovery data.

2. A tagging study and observation of fishermen's catches indicated that commercial-size male crabs remained in the river until fall, whereas 44% of the females migrated to the more saline waters of Pamlico Sound precluding their capture in the river.

3. Estimates of daily recruitment rates were calculated from the ratios of precommercial (crabs 3.4 to 4.5 inches carapace width) to commercial-size crabs (>4.5 inches) in samples of unculled crabs obtained from commercial fishermen.

4. The first of three methods used to estimate population size was the Leslie method (Leslie and Davis, 1939). To satisfy the conditions for a closed population, only catch and effort data for male crabs, reduced by the estimated weight of male recruits, were used. From the estimates of the male crab population, estimates for the total population were obtained by using the ratios of male to female crabs in the catch. Minimal 95% confidence limits for the total population on 7 July, 716,000 pounds, were 660,000 and 801,000 pounds.

5. The second method of population estimation also employed catch, effort, and recruitment data. Using this method, an estimate of the population on 12 May was calculated. By successive substitution of the catch and estimated recruitment rates during the weeks following 12 May, an estimate of the population on 7 July, 703,000 pounds, was obtained.

6. The third method involved the plot of transformed ratios of tagged to untagged crabs, caught daily, against the number of days after cessation of tagging (Parker, 1955). The 95% confidence limits for the estimate on 4 July, 722,000 pounds, were 516,000 and 1,009,000 pounds.

7. During 1958, it is estimated that 2.14 million pounds of crabs were available to the fishery in the Neuse River. Of this population, 1.63 million pounds were caught by the three major types of gear prior to 22 September; the remainder, 0.51 million pounds, is the estimate of the population on 22 September. The amount of recruitment for the remainder of the crabbing season after 22 September was negligible.

8. The effects of wind speed and direction as well as competition between fishing vessels on catchability were considered negligible throughout most of the fishing season.

9. The possibilities of (1) natural mortality of tagged and untagged crabs, (2) fish predation upon crabs, and (3) loss of tags by molting crabs sizably affecting the crab population or the estimates, were considered remote.

10. The ratios by weight of the daily catch of soft to hard crabs agreed with the recruitment rates calculated from the ratios of precommercial- to commercial-size crabs in the catch samples.

11. Estimates of the average daily instantaneous recruitment rate were derived from the Parker (1955) method for estimating population size. The high rates obtained were due not only to recruitment, but to changing availability of tagged and untagged crabs.

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## LITERATURE CITED

COSTLOW, JOHN D., AND C. G. BOOKHOUT. 1959. The larval development of *Callinectes sapidus* Rathbun reared in the laboratory. Biol. Bull. 116 (3): 373–396.

DARNELL, REZNEAT M. 1959. Studies of the life history of the blue crab (*Callinectes sapidus*) in Louisiana waters. Trans. Amer. Fish. Soc. 88(4): 294–304.

DELURY, D. B. 1947. On the estimation of biological populations. Biometrics 3: 145–167.

———. 1951. On the planning of experiments for the estimation of fish populations. J. Fish. Res. Bd. Canada 8 (4): 281–307.

GRAY, ELLEN H., AND CURTIS L. NEWCOMBE. 1939.

Studies on molting in *Callinectes sapidus* Rathbun. Growth 2: 285–296.

Leslie, P. H., and D. H. S. Davis. 1939. An attempt to determine the absolute number of rats on a given area. J. Anim. Ecol. 8: 94–113.

Nose, Yukio. 1961. On the Petersen-type estimate of fish population under the existence of recruitment. Bull. Jap. Soc. Sci. Fish. 27(10): 881–892. (Translated from Japanese by Wan Soo Kim, University of Washington, College of Fisheries, Fish. Res. Inst., Circ. 187, 1963.)

Parker, Richard A. 1955. A method for removing the effect of recruitment on Petersen-type population estimates. J. Fish. Res. Bd. Canada 12(3): 447–450.

———. 1963. On the estimation of population size, mortality, and recruitment. Biometrics 19: 318–323.

Pearson, John C. 1951. The blue crab in North Carolina. *In* Harden F. Taylor and Associates, "Survey of Marine Fisheries of North Carolina." The University of North Carolina Press, Chapel Hill, North Carolina, p. 205–250.

Porter, Hugh J. 1956. Delaware blue crab. Estuarine Bull., Univ. Delaware Marine Lab. 2(2): 3–5.

Ricker, W. E. 1958. Handbook of computations for biological statistics of fish populations. Fish. Res. Bd. Canada, Bull. No. 119, 300 p.

Roelofs, Eugene W. 1950. Mesh size and construction as a factor in releasing small fish and shrimp from trawl nets. U. S. Fish and Wildl. Serv., Comm. Fish. Rev. 12(8): 1–11.

———. 1954. Food studies of young Sciaenid fishes, *Micropogon* and *Leiostomus*, from North Carolina. Copeia (2): 151–153.

Rounsefell, G. A., and W. H. Everhart. 1953. Fishery science; its methods and applications. John Wiley & Sons, New York, 444 p.

Snedecor, G. W. 1956. Statistical methods. 5th edition, Iowa State College Press, Ames, Iowa, 534 p.

Truitt, R. V. 1939. The blue crab. *In* Our water resources and their conservation. Contrib. Chesapeake Biol. Lab. 27: 10–38.

Van Engel, W. A. 1958. The blue crab and its fishery in Chesapeake Bay—Part 1—Reproduction, early development, growth, and migration. U. S. Fish and Wildl. Serv., Comm. Fish. Rev. 20(6): 6–17.

———. 1962. The blue crab and its fishery in Chesapeake Bay—Part 2—Types of gear for hard crab fishing. U. S. Fish and Wildl. Serv., Comm. Fish. Rev. 24(9): 1–10.

Wharton, James. 1954. The Chesapeake Bay crab industry. U. S. Fish and Wildl. Serv., Fishery Leaflet 358 (Revised): 1–17.

# PELAGIC FUR SEAL RESEARCH IN THE EASTERN PACIFIC

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After preparations begun in 1948, the Interim Convention on Conservation of North Pacific Fur Seals was signed in February 1957. The Convention's objectives for pelagic research included a study of distribution and food habits. A Protocol amending the Convention, signed in October 1964, added research on the effectiveness of land and pelagic sealing for management and on the quality of sealskins. The U. S. and Canada began annual pelagic investigations in February 1958. From 1958 to 1963, 8, 739 seals were collected by the U. S. Investigations were made off California, Oregon and Washington from November to June, and in Alaskan waters from February to October. The proportion of seals with U. S. tags taken pelagically increased from 1. 2 percent in 1959 to 4. 8 in 1964. Evidence of intermingling between seals of Asian and American origins in the eastern Pacific is inconclusive. Fifty species of fish and seven species of cephalopods have been identified from seal stomachs. Feeding areas were located off central California, in the Gulf of Alaska, south of Unimak Pass, and in the Bering Sea.

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# AVOIDANCE OF TOWED NETS BY ZOOPLANKTON

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# AVOIDANCE OF TOWED NETS BY ZOOPLANKTON[1]

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ABSTRACT

Experiments were conducted to determine the effect of behavior on the accuracy of sampling populations composed of several species of marine copepods and mysids held in a large, enclosed seawater pool. Plankton nets having mouth areas of 1,600, 800, and 400 cm$^2$ were towed in replicate sets during midday and midnight under three light conditions in plankton populations of different densities. Statistical treatment of the results showed that smaller nets were more effectively avoided and that the degree of avoidance varied among species. Estimates of the peripheral escape zone were obtained. More mysids, but not more copepods, were caught in darkness than in light, and avoidance tended to be less in denser populations. Time of day had no effect on avoidance behavior. Escape mechanisms and the possible effect of population density are discussed.

## INTRODUCTION

Evaluation of plankton populations in the sea requires sampling and thus involves uncertainty that may affect both precision and accuracy. Contagious distribution of organisms decreases precision, while sampling gear performance and the reactions of the organisms affect the accuracy of estimates of population densities.

The proposition that zooplankton avoid nets is not new; for example, Franz (1910) suggested that plankton capable of seeing an oncoming net in daylight would avoid capture, Mackintosh (1934) observed euphausiids avoiding a net near the surface, Bary et al. (1958) suggested that plankters may avoid nets if there is a zone of pressure preceding the net, and Hansen and Andersen (1962) contended that nets are grossly inefficient for catching copepods. By contrast, Winsor and Clarke (1940) implied that avoidance was not a problem in that they concluded that a 12.7-cm-diameter net was as reliable as a 75-cm net for sampling the copepod species that they considered.

The work reported here, part of a continuing study of the causes of variability in plankton sampling, deals only with the accuracy of net sampling for zooplankton as affected by the behavior of the animals themselves. These experiments were conducted on captive populations of zooplankton to eliminate several problems adversely affecting field collections: 1) the effects of vertical migration, 2) large-scale patchiness in the distribution of organisms, and 3) variation in vessel speed and drift. Moreover, it allowed for factorial experimental design wherein light conditions, time of sampling, and course of sampling could be precisely repeated.

We conclude that zooplankton can avoid capture to such an extent that accuracy is affected and that both visual and mechanical disturbances can be involved.

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## METHODS

The experiments were conducted in a large rectangular concrete pool (Fig. 1) that had been exposed to seawater for

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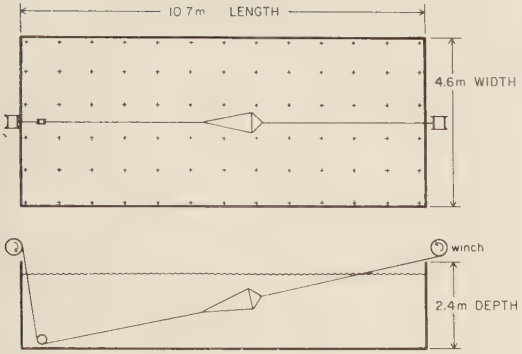
10.7m LENGTH
4.6m WIDTH
winch
2.4m DEPTH

FIG. 1. Diagram of experimental pool illustrating (above) arrangement of overhead lights (+) and (below) method of towing nets.

several years. It was enclosed by an essentially lighttight superstructure; interior illumination was provided by 78 100-w incandescent lamps placed 3.04 m (10 ft) above the water surface at 0.91-m (3-ft) intervals and controlled by rheostats.

The pool was filled with unfiltered seawater pumped through an opaque plastic pipe from an intake 300 m offshore, about 3 m below the sea surface at mean tide level and 3 m above the sea floor. Thus, it was possible to introduce experimental zooplankton populations without directly handling the animals. Populations of different densities were obtained by allowing the water to overflow at the surface under full illumination for different time periods. Tests showed that significantly more animals entered the pool than were lost in the outflow under these conditions. The plankton was allowed to acclimate for one week preceding the start of experimentation. The animals remained vigorous; delicate fish larvae and chaetognaths survived, and copepods reproduced.

Three conical plankton nets (Fig. 2) having mouth areas of 1,600, 800, and 400 cm², and proportional in all other dimensions, were used in the study. The towing bridles were constructed of three strands of 1.7-mm-diameter plastic-coated steel cable; forward extension of each bridle was equal to the mouth diameter of the net to which it was attached. To overcome the effect of any variation in vertical distribution of the animals, net tows were made obliquely from the bottom of the pool to the surface of the water (Fig. 1). A constant towing rate of 30 cm (1 ft)/sec was used. The line of traverse was kept straight by the use of a restraining line. The hauling line was made of 2.4-mm (3/32-inch) hydrographic wire. Since the tows were short and the nets were washed thoroughly as well as being towed backward to the starting position after each haul, clogging was not a

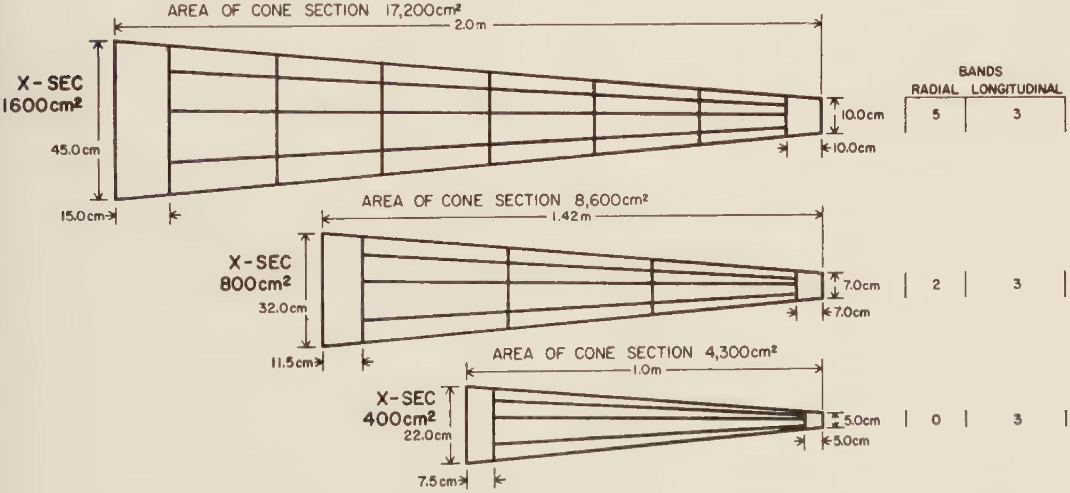
AREA OF CONE SECTION 17,200cm²
2.0m
X-SEC
1600cm²
45.0cm
15.0cm
10.0cm
10.0cm
BANDS
RADIAL
LONGITUDINAL
5
3
AREA OF CONE SECTION 8,600cm²
1.42m
X-SEC
800cm²
32.0cm
11.5cm
7.0cm
7.0cm
2
3
AREA OF CONE SECTION 4,300cm²
1.0m
X-SEC
400cm²
22.0cm
7.5cm
5.0cm
5.0cm
0
3

FIG. 2. Diagram of experimental plankton nets used in study, showing construction specifications. Filtering material of 333-μ aperture monofilament nylon, collars and bands of dacron.

TABLE 1. *Basic design for each of the six sampling experiments*

| Net | Full light | Reduced light | Dark |
|---|---|---|---|
| 1,600 cm$^2$ | 2 trials | 2 trials | 2 trials |
| 800 cm$^2$ | 2 trials | 2 trials | 2 trials |
| 400 cm$^2$ | 2 trials | 2 trials | 2 trials |

problem. The nets were left in the starting position on the bottom for 10 min before each tow, and 10 additional minutes were allowed after changes in light intensity. Actual filtration efficiency was not determined. The three nets strained theoretical maxima of 0.8, 0.4, and 0.2 m$^3$ of water per haul.

Six experiments were carried out according to the balanced design shown in Table 1, full light intensity was about 550 lux at the water surface, and reduced light intensity about 22 lux. Three experiments were carried out on 5–6 July 1961 and three on a different population on 13–14 July 1961. The 13–14 July population was made larger to test the possible effect of population density on avoidance behavior. Two midday (1200–1600 hours) and one midnight (2200–0200 hours) experiments were carried out on each population. All three light conditions were imposed in each experiment. The night series were included to test for possible endogenous diurnal changes in activity of the animals.

The animals in the total of 108 samples were examined and counted under a stereomicroscope at 16× magnification.

TABLE 2. *Species and size ranges of zooplankton included in the analyses*

| Species | Body length (mm) |
|---|---|
| Copepoda | |
| *Acartia clausi* | 0.80–1.10 |
| *Acartia tonsa* | 0.90–1.20 |
| *Calanus helgolandicus* | 2.50–3.50 |
| *Corycaeus anglicus* | 0.85–1.10 |
| *Oithona* spp. | 0.70–0.90 |
| *Paracalanus parvus* | 0.75–1.00 |
| Mysidacea | |
| *Metamysidopsis elongata* | 1.50–5.50 |

TABLE 3. *Sums of actual and adjusted* numbers of copepods and mysids caught in four experiments, including two midday and two midnight experiments*

| Group | Actual catches | | Adjusted catches | |
|---|---|---|---|---|
| | Day | Night | Day | Night |
| Copepoda | | | | |
| 5–6 July | 2,580 | 2,545 | 3,565 | 3,187 |
| 13–14 July | 16,233 | 15,599 | 25,315 | 22,664 |
| Total | 18,813 | 18,144 | 28,880 | 25,851 |
| Mysidacea | | | | |
| 5–6 July | 74 | 57 | 121 | 76 |
| 13–14 July | 560 | 608 | 856 | 975 |
| Total | 634 | 665 | 977 | 1,051 |

* Sums computed after data for 800- and 400-cm$^2$ nets were adjusted to number of individuals per 0.8 m$^3$ for each sample.

## RESULTS

The animals included in this analysis and their size ranges are listed in Table 2. Two other, less abundant, copepods were taken, along with a chaetognath and fish larvae, but their occurrence was too sporadic to include them in the analysis. Two species of mysids occurred in the samples; the second species, *Mysidopsis californica* (juveniles), was not distinguished from *Metamysidopsis elongata* in the sample counts, but it never composed more than about 5% of the mysid population.

It was first necessary to determine if significant diurnal changes in activity occurred or if the midnight and midday experiments could be considered equal. The night and preceding day samples were compared by an analysis of variance. The sums of the numbers of copepods and mysids in these samples are given in Table 3. Before the analysis, sample data for the 800- and 400-cm$^2$ nets were multiplied by 2 and 4, respectively, to correspond to the number of individuals per 0.8 m$^3$ of water strained, that is, equivalent to the catch of the 1,600-cm$^2$ net, and all values were normalized by being transformed to logarithms (Barnes 1952). Complete partition of the variance was not made, but neither copepods nor mysids showed any evidence of diurnal

TABLE 4. *Mean adjusted catch per haul of six replicate hauls for each net and light condition, listed by species for the two populations*

| Population | Net | Light condition | *Acartia clausi* | *Acartia tonsa* | *Calanus helgolandicus* | *Corycaeus anglicus* | *Oithona* spp. | *Paracalanus parvus* | Mysidacea |
|---|---|---|---|---|---|---|---|---|---|
| 5–6 July | 1,600 cm² | Full | 229.3 | 88.7 | 22.8 | 3.7 | 22.7 | 32.7 | 12.8 |
| | | Reduced | 198.2 | 77.3 | 22.3 | 2.3 | 13.0 | 24.7 | 7.8 |
| | | Dark | 151.0 | 62.3 | 20.5 | 3.2 | 2.7 | 22.7 | 13.3 |
| | 800 cm² | Full | 70.7 | 40.0 | 12.3 | 1.7 | 16.7 | 8.0 | 6.3 |
| | | Reduced | 95.3 | 49.0 | 13.7 | 1.7 | 6.7 | 7.3 | 6.7 |
| | | Dark | 78.3 | 46.0 | 20.3 | 0.7 | 2.0 | 10.7 | 10.0 |
| | 400 cm² | Full | 34.0 | 22.7 | 6.0 | 0.7 | 3.3 | 2.0 | 2.0 |
| | | Reduced | 51.3 | 20.0 | 8.7 | 0.0 | 5.3 | 1.3 | 2.0 |
| | | Dark | 29.3 | 10.0 | 8.7 | 0.0 | 0.0 | 2.7 | 4.7 |
| 13–14 July | 1,600 cm² | Full | 281.5 | 1,001.5 | 7.2 | 123.7 | 156.2 | 228.5 | 17.5 |
| | | Reduced | 276.7 | 933.3 | 2.5 | 88.3 | 123.3 | 217.5 | 30.3 |
| | | Dark | 286.7 | 967.5 | 3.5 | 87.5 | 175.8 | 156.7 | 154.8 |
| | 800 cm² | Full | 126.7 | 605.7 | 5.7 | 34.3 | 72.0 | 45.7 | 15.7 |
| | | Reduced | 124.0 | 496.3 | 3.7 | 31.0 | 100.7 | 38.7 | 19.3 |
| | | Dark | 156.7 | 685.7 | 4.3 | 39.7 | 79.3 | 49.3 | 123.7 |
| | 400 cm² | Full | 70.7 | 673.3 | 2.0 | 14.7 | 118.7 | 37.3 | 16.0 |
| | | Reduced | 105.3 | 828.0 | 4.7 | 18.7 | 118.7 | 37.3 | 28.0 |
| | | Dark | 80.7 | 495.3 | 7.3 | 29.3 | 107.3 | 36.0 | 71.3 |

changes in activity. Therefore, the two midday experiments and the one midnight experiment could be treated as replicates.

Table 4 shows, by species, the adjusted mean number of individuals per haul for each replicate set of samples.

The mean numbers of mysids per haul, partitioned in various ways, for all six experiments are given in Table 5. The results of analysis of variance of the data are given in Table 6; the unpartitioned residual variance was used for the error term in calculating variance ratios. As expected, the population sampled on 13–14 July yielded a significantly larger mean catch than the population sampled on 5–6 July. The replicates were not significantly different, indicating no inconsistencies in sampling technique. Changes in light intensity had a significant effect on sampling for mysids; many more were caught in darkness. The two smaller nets took significantly fewer animals per theoretical unit volume sampled than did the largest net. Interaction between population size and net size was significant, suggesting that avoidance tended to be less in the denser population. The significant interaction between population size and light condition was due to a higher ratio of catches in the dark to catches in the light in the larger population.

Similar data for copepods are given in Tables 7 and 8. The differences between means for species were expected because of the known differences in abundance of

TABLE 5. *Mean values of actual number of mysids caught in 108 hauls*

| | Mean number per haul |
|---|---|
| Populations | |
| 5–6 July | 5.3 |
| 13–14 July | 34.5 |
| Nets | |
| 1,600 cm² | 39.4 |
| 800 cm² | 15.1 |
| 400 cm² | 5.2 |
| Light conditions | |
| Full light | 7.6 |
| Reduced light | 9.8 |
| Darkness | 42.3 |
| Replicates | |
| First trial | 18.2 |
| Second trial | 21.6 |
| Third trial | 17.8 |
| Fourth trial | 20.1 |
| Fifth trial | 23.3 |
| Sixth trial | 18.6 |

TABLE 6. *Analysis of variance for mysids caught in 108 hauls**

| Source of variation | Degrees of freedom | Variance ratio† | Probability higher value by chance |
|---|---|---|---|
| Populations | 1 | 148.2 | $<0.0005$ |
| Nets | 2 | 11.8 | $<0.0005$ |
| Light conditions | 2 | 30.8 | $<0.0005$ |
| Replicates | 5 | 1.3 | 0.25–0.50 |
| Population–net interaction | 2 | 6.7 | $<0.005$ |
| Population–light interaction | 2 | 11.5 | $<0.0005$ |
| Net–light interaction | 4 | 0.4 | 0.75–0.90 |

* Data for 800- and 400-$cm^2$ nets adjusted to number of individuals per 0.8 $m^3$ for each sample and all data transformed to logarithms before analysis.

† Mean square for stated source divided by residual mean square of 0.513 (89 degrees of freedom).

TABLE 7. *Mean values of actual number of copepods caught in 108 hauls*

| | Mean number per haul |
|---|---|
| Species | |
| *Acartia clausi* | 102.3 |
| *Acartia tonsa* | 255.8 |
| *Calanus helgolandicus* | 6.6 |
| *Corycaeus anglicus* | 21.0 |
| *Oithona* spp. | 40.0 |
| *Paracalanus parvus* | 44.0 |
| Populations | |
| 5–6 July | 143.5 |
| 13–14 July | 796.0 |
| Nets | |
| 1,600 $cm^2$ | 1,019.6 |
| 800 $cm^2$ | 265.0 |
| 400 $cm^2$ | 124.6 |
| Light conditions | |
| Full light | 494.0 |
| Reduced light | 460.5 |
| Darkness | 454.7 |
| Replicates | |
| First trial | 538.4 |
| Second trial | 512.1 |
| Third trial | 424.9 |
| Fourth trial | 410.3 |
| Fifth trial | 474.3 |
| Sixth trial | 461.4 |

these species in the populations. Based on catches, the population sampled on 13–14 July was significantly larger than the 5–6 July population, as intended. The six means for replicates were not significantly different from one another. Unlike the case of the mysids, changes in light intensity had no significant effect on sampling copepods. Like that of the mysids, the two smaller nets took significantly fewer animals per unit volume of water strained than the largest net. This apparent avoidance differed among species, as indicated by the significant variance ratio for interaction between species and net size. A separate analysis has shown that even the two species of *Acartia* reacted differently from each other. The significant interaction between population size and net size suggests that avoidance tended to be less in the denser populations.

Since the analysis for copepods is a simultaneous treatment of six species, it does not show the contribution of individual species to the variations among net catches. The apparent reaction of each species was tested separately by analysis of variance of the adjusted catches (number per 0.8 $m^3$ of water sampled) of the three nets (Table 9). In 25 of 36 comparisons, the smaller nets took significantly fewer animals than expected, the most notable exceptions being *Calanus helgolandicus* (13–14 July) and *Oithona* spp. (5–6 July). In 5 of 12 comparisons, the catch per unit volume of the smallest net was significantly less than that of the intermediate net. In no case did the catch of a smaller net significantly exceed that of a larger one.

We cannot precisely evaluate the distances moved by the test animals in avoiding capture without detailed knowledge of their escape behavior. Nevertheless, the apparent minimum peripheral escape zone can be calculated by comparing the catches of the smaller nets with those of the larger net. The width of this peripheral escape zone, here called $\Delta r$, is determined by assuming that the "effective" sampling areas

TABLE 8. *Analysis of variance for copepods caught in 108 hauls**

| Source of variation | Degrees of freedom | Variance ratio† | Probability higher value by chance |
|---|---|---|---|
| Species | 5 | 140.7 | $<0.0005$ |
| Populations | 1 | 449.9 | $<0.0005$ |
| Nets | 2 | 239.8 | $<0.0005$ |
| Light conditions | 2 | 0.7 | 0.50–0.75 |
| Replicates | 5 | 0.6 | 0.50–0.75 |
| Species–net interaction | 10 | 15.7 | $<0.0005$ |
| Species–light interaction | 10 | 0.8 | 0.50–0.75 |
| Population–net interaction | 2 | 3.7 | 0.025 |
| Net–light interaction | 4 | 1.3 | 0.25–0.50 |

* Data for 800- and 400-cm² nets adjusted to number of individuals per 0.8 m³ for each sample and all data transformed to logarithms before analysis.

† Mean square for stated source divided by residual mean square of 1.06 (606 degrees of freedom).

TABLE 9. *Results of analyses of variance for differences within species of copepods of numbers caught per 0.8 m³ with nets of three sizes**

| Species | Population | Nets (cm²) compared | | |
|---|---|---|---|---|
| | | 1,600–800 | 1,600–400 | 800–400 |
| *Acartia clausi* | 5–6 July | + | + | + |
| | 13–14 July | + | + | + |
| *Acartia tonsa* | 5–6 July | + | + | + |
| | 13–14 July | + | + | 0 |
| *Calanus helgolandicus* | 5–6 July | + | + | + |
| | 13–14 July | 0 | 0 | 0 |
| *Corycaeus anglicus* | 5–6 July | + | + | 0 |
| | 13–14 July | + | + | 0 |
| *Oithona* spp. | 5–6 July | 0 | 0 | 0 |
| | 13–14 July | + | + | 0 |
| *Paracalanus parvus* | 5–6 July | + | + | + |
| | 13–14 July | + | + | 0 |

* Employing the method of Tukey (1953). The symbol + indicates that the catch of the larger net was significantly greater, and the symbol 0 indicates no significant difference at the 5% confidence level.

of the smaller nets are proportional to their catches, that is,

$$\pi \hat{r}^2 = \pi r_L^2 \frac{C_s}{C_L},$$

where

$\hat{r}$ = effective radius of the smaller (800- or 400-cm²) net,

$r_L$ = radius of 1,600-cm² net,

$C_s$ = catch of smaller (800- or 400-cm²) net,

$C_L$ = corresponding catch of 1,600-cm² net.

By definition,

$$\Delta r = r_s - \hat{r},$$

where

$\Delta r$ = minimum width of peripheral escape zone,

$r_s$ = actual radius of the smaller (800- or 400-cm²) net.

Therefore,

$$\Delta r = r_s - r_L (C_s/C_L)^{1/2}.$$

This calculation was made for the two smaller nets for each species population independently, giving the results summarized in Table 10. Combining nets and populations, the mean values for $\Delta r$ (cm) for each species are: *Acartia clausi*, 5.4; *Acartia tonsa*, 3.8; *Calanus helgolandicus*, 1.6; *Corycaeus anglicus*, 6.8; *Oithona* spp., 3.6; and *Paracalanus parvus*, 7.2. The calculated minimum width of the peripheral escape zone is not significantly correlated with body length (*see* Table 2). The rank correlation statistic (Tate and Clelland 1957) is $\tau = 0.13$; the probability that a higher absolute value may occur by chance is greater than 20%.

## DISCUSSION

In these experiments, the larger nets caught more copepods and mysids per theoretical unit volume of water filtered than the smaller nets. We have no reason to believe that filtration efficiency differed among the nets under the conditions of the experiment. Since the largest net used presumably did not sample with 100% efficiency, the interpretation of significant differences in catches is probably conservative.

Vulnerability to capture under full and reduced light conditions differed significantly between mysids and copepods. For mysids, but not for copepods, apparent avoidance was greater in light than in darkness. This could be attributed to dissimilar visual acuity. The mysids have well-developed compound eyes, whereas the eyes of the copepods are capable of light perception but probably not of image formation. Smaller catches of mysids in light could have resulted from better perception of the moving net, towline, and bridle. Alternatively, they could have resulted from changes in the distribution of the animals preceding the actual tow. In a lighted medium, the mysids habitually remain within 5–20 cm of the bottom and also shun foreign objects. If the area around the net was evaded by mysids that otherwise crowded close to the bottom of the pool, an oblique tow would fail to sample representatively the densest stratum of the population. This may not have occurred in darkness, either because the immobile net was not avoided or because of the tendency for the animals to become more dispersed vertically in darkness.

Although the effect of bioluminescence was not determined, the moving nets were visible as glowing cones during all of the tows made in darkness. This may have affected dark sampling for both copepods and mysids.

Since all samples were taken with nets preceded by bridles and a long towing line, it is possible that the animals merely reacted to tactile or vibrational stimuli, or, alternatively, to pressure waves formed ahead of the moving nets. According to Brook and Woodward (1956), the reaction of copepods to rapidly accelerating currents is a function of hydrostatic pressure change. Both mysids and copepods are responsive to changes in hydrostatic pressure (Knight-Jones and Quasim 1955; Rice 1961, 1962), but the response times may not be short enough to allow the animals to use this cue in avoiding sampling devices. Enright (1962) found that single square pressure waves must include at least a full second of increased pressure to produce appreciable response in an amphipod.

Zooplankton may be oriented initially in any direction relative to the trajectory of a sampling device and still disperse away from the path of the device so long as a gradient in intensity of the cue, or of the reaction to it, occurs in the vicinity of the trajectory. However, avoidance will be increased if the animals are capable of oriented movement.

Storch (1929) and Lowndes (1935) describe escape swimming in calanoids as a darting movement produced by repeated backward flexure of the biramous thoracic legs. Lowe (1935) has presented morphological evidence of a system of giant nerve fibers in *Calanus* that supply the muscles used in rapid leaping, escape movements. She argues convincingly that a stimulus applied differentially to the paired sensory receptors (thought to be the first antennae) will cause this darting movement to be directed away from the source of stimulation. We have observed a variety of calanoid species exhibiting darting movements away from the mouth of a pipette being used to capture them. We have also observed that the mysids used in this study are capable of well-oriented escape movements.

The lack of significant correlation between copepod body length and the estimated width of the peripheral escape zone does not support the report by Lukjanova (1940) that when different species are compared, the velocities of movement of marine planktonic copepods are proportional to the cube roots of their lengths. *Calanus helgolandicus* was the largest copepod sampled in our study, but it gave the least evidence of avoidance of all six copepod species. However, the degree of avoidance may not be directly related to swimming capability but to a general reaction pattern characteristic of the species. We have found that *Calanus finmarchicus* may show little response to displacement by a current that is simultaneously strongly opposed by the copepod *Temora longicornis*. Knight-Jones and Quasim (1955) failed to obtain clear pressure responses in *Calanus* while at the same time obtaining them from another copepod, *Caligus rapax*, and Rice (1962) found the responses of *Calanus helgolandicus* to pressure to be unpredictable.

The swimming velocities of marine copepods have been estimated to be between 0.7 cm/sec and 12 cm/sec by Welsh (1933), Hardy and Bainbridge (1954), and Nishigawa, Fukuda, and Inoue (1954). The highest of the estimated velocities are probably sufficient to allow significant avoidance of nets among disturbed animals, but the observations included cruising velocities and therefore are not applicable directly to escape behavior. Lukjanova (1940) reported more directly applicable maximum velocities of up to 15 cm/sec for *Anomalocera*, and Lowndes (1933) observed a rate of 20 cm/sec for *Diaptomus gracilis*. By applying the velocity data of Storch (1929), Lochhead (1961) calculated that speeds for each jump in excess of the 20 cm/sec reported for *Diaptomus* should certainly be possible. Recent analysis of slow-motion films (P. E. Smith, Bureau of Commercial Fisheries Biological Laboratory, La Jolla, personal communication) has shown that, when being attacked by fish, the copepod *Labidocera acutifrons* is capable of directed movement at a rate of 80 cm/sec (230 body lengths/sec) over distances of at least 15 cm. At this rate, a copepod would take only 0.1 sec to pass through the broadest peripheral escape zone estimated in this study (*see* Table 10).

The sampling results show that relatively more animals were taken in the smaller nets than in the larger net, and in the denser population than in the less dense population. This suggests that interindividual interference may have restricted their movements. If we assume that 1) the animals were randomly distributed in the pool and 2) physical contact was necessary for interference to occur, we find that the mean free path of the animals is on the order of 25 m or more, even in the denser population. The probability of contact in a path 16 cm long (the radius of the intermediate size net) would thus be $< 0.007$ in the denser population. Thus, the animals either experienced effective contact by other than tactile means, or their aggregation increased the probability of contact.

It is concluded that accuracy in sampling can be affected significantly by the behavior of the animals themselves. To collect representative cross sections of the zooplankton community, or to make accurate estimates of the population structure of any given species, it will be necessary to use sampling devices with minimal escape cues, and with mouth areas or towing velocities, or both, that are adequate to overcome the escape capabilities of the animals sought. This will require further background studies on the general behavior and locomotor capabilities of representative species of the plankton community.

TABLE 10. *Estimates of width of peripheral escape zone* (Δr) *for copepods*

| Species | Population | Net (cm$^2$) | Δr (cm) |
|---|---|---|---|
| *Acartia clausi* | 5–6 July | 800 | 5.6 |
| | | 400 | 6.0 |
| | 13–14 July | 800 | 5.0 |
| | | 400 | 4.9 |
| *Acartia tonsa* | 5–6 July | 800 | 3.7 |
| | | 400 | 5.7 |
| | 13–14 July | 800 | 3.4 |
| | | 400 | 1.9 |
| *Calanus helgolandicus* | 5–6 July | 800 | 2.6 |
| | | 400 | 4.4 |
| | 13–14 July | 800 | 0.3 |
| | | 400 | 0.5 |
| *Corycaeus anglicus* | 5–6 July | 800 | 6.4 |
| | | 400 | 8.1 |
| | 13–14 July | 800 | 6.6 |
| | | 400 | 5.9 |
| *Oithona* spp. | 5–6 July | 800 | 3.0 |
| | | 400 | 5.7 |
| | 13–14 July | 800 | 4.2 |
| | | 400 | 1.4 |
| *Paracalanus parvus* | 5–6 July | 800 | 5.9 |
| | | 400 | 7.9 |
| | 13–14 July | 800 | 8.5 |
| | | 400 | 6.4 |

## REFERENCES

BARNES, H. 1952. The use of transformations in marine biological statistics. J. Conseil, Conseil Perm. Intern. Exploration Mer, **18**: 61–71.

BARY, B. M., J. G. DE STEFANO, M. FORSYTH, AND J. VAN DEN KERKHOF. 1958. A closing, high speed plankton catcher for use in vertical and horizontal towing. Pacific Sci., **12**: 46–59.

BROOK, A. J., AND W. B. WOODWARD. 1956. Some observations on the effects of water inflow on the plankton of small lakes. J. Animal Ecol., **25**: 22–35.

ENRIGHT, J. T. 1962. Responses of an amphipod to pressure changes. Comp. Biochem. Physiol., **7**: 131–145.

FRANZ, V. 1910. Phototaxis und Wanderung. Nach Versuchen auf Jungfischen und Fischlarven. Intern. Rev. ges. Hydrobiol., **3**: 306–334.

HANSEN, V. K., AND K. P. ANDERSEN. 1962. Sampling the smaller zooplankton. Rappt. Proces-Verbaux Reunions, Conseil Perm. Intern. Exploration Mer, **153**: 39–47.

HARDY, A. C., AND R. BAINBRIDGE. 1954. Experimental observations on the vertical migration of plankton animals. J. Marine Biol. Assoc. U.K., **33**: 409–448.

KNIGHT-JONES, E. W., AND S. Z. QUASIM. 1955. Responses of some marine plankton animals to changes in hydrostatic pressure. Nature, **175**: 941–942.

LOCHHEAD, J. H. 1961. Locomotion, p. 313–364, v. 2. *In* T. H. Waterman [ed.], The physiology of Crustacea. Academic, New York and London.

LOWE, E. 1935. On the anatomy of a marine copepod, *Calanus finmarchicus* (Gunnerus). Trans. Roy. Soc. Edinburgh, **58**: 561–603.

LOWNDES, A. G. 1933. The feeding mechanism of *Chirocephalus diaphanus* Prévost, the fairy shrimp. Proc. Zool. Soc. London, **1933**: 1093–1118.

———. 1935. The swimming and feeding of certain calanoid copepods. Proc. Zool. Soc. London, 1935: 687–715.

LUKJANOVA, W. S. 1940. On the maximum velocities of marine plankters. Compt. Rend. (Doklady) Acad. Sci. URSS N.S., **28**: 641–644.

MACKINTOSH, N. A. 1934. Distribution of the macroplankton in the Atlantic sector of the Antarctic. Discovery Rept., **9**: 65–160.

NISHIGAWA, S., M. FUKUDA, AND N. INOUE. 1954. Photographic study of suspended matter and plankton in the sea. Bull. Fac. Fisheries, Hokkaido Univ., **5**: 36–40.

RICE, A. L. 1961. The responses of certain mysids to changes in hydrostatic pressure. J. Exp. Biol., **38**: 391–401.

———. 1962. Responses of *Calanus finmarchicus* (Gunn.) to changes of hydrostatic pressure. Nature, **194**: 1189–1190.

STORCH, O. 1929. Die Schwimmbewegung der Copepoden, auf Grund von Mikro-Zeitlupenaufnahmen analysiert. Verhandl. Deut. Zool. Ges., **33**: 118–129.

TATE, M. W., AND R. C. CLELLAND. 1957. Nonparametric and shortcut statistics. Interstate Printers and Publishers, Danville, Illinois.

TUKEY, J. W. 1953. Some selected quick and easy methods of statistical analysis. Trans. N.Y. Acad. Sci. Ser. 2, **16**: 88–97.

WELSH, J. H. 1933. Light intensity and the extent of activity of locomotor muscles as opposed to cilia. Biol. Bull., **65**: 168–174.

WINSOR, C. P., AND G. L. CLARKE. 1940. A statistical study of variation in the catch of plankton nets. J. Marine Res., **3**: 1–34.

# INTER-AMERICAN TROPICAL TUNA COMMISSION
# COMISION INTERAMERICANA DEL ATUN TROPICAL

Bulletin-Boletin
Vol. 10, No. 2

## OCEANOGRAPHIC OBSERVATIONS FROM THE EASTERN PACIFIC OCEAN COLLECTED BY THE R/V *SHOYO MARU*, OCTOBER 1963-MARCH 1964

## OBSERVACIONES OCEANOGRAFICAS DEL OCEANO PACIFICO ORIENTAL RECOLECTADAS POR EL BARCO *SHOYO MARU*, OCTUBRE 1963-MARZO 1964

**by — por**
**ERIC D. FORSBERGH and/y WILLIAM W. BROENKOW**

La Jolla, California
1965

The **Inter-American Tropical Tuna Commission** was established by a Convention between the Governments of the Republic of Costa Rica and the United States of America. The Convention entered into force in 1950. The Commission's duties under the Convention (Art. II, 1.) include the conduct of:

> "investigations concerning the abundance, biology, biometry, and ecology of yellowfin (*Neothunnus*) and skipjack (*Katsuwonus*) tuna in the waters of the eastern Pacific Ocean . . . and the kinds of fishes commonly used as bait in the tuna fisheries . . . and of other kinds of fish taken by tuna fishing vessels; and the effects of natural factors and human activities on the abundance of the populations of fishes supporting all of these fisheries."

and to

> "Recommend from time to time, on the basis of scientific investigations, proposals for joint action . . . designed to keep the populations of fishes covered by this Convention at those levels of abundance which will permit the maximum sustained catch."

The Commission initiated its investigations, which are conducted by a permanent international scientific staff, in 1951.

Provision is made in the Convention (Art. V, 3.) for:

> "Any government, whose nationals participate in the fisheries covered by this Convention . . . Upon receiving the unanimous consent of the High Contracting Parties . . ."

to adhere. Under this provision the Republic of Panama adhered in 1953, the Republic of Ecuador in 1961, and the United Mexican States in 1964.

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> "Llevar a cabo investigaciones sobre la abundancia, biología, biometría y ecología de los atunes de aletas amarillas (*Neothunnus*) y bonitos (*Katsuwonus*) de las aguas del Pacífico Oriental . . . como también de las clases de pescado que generalmente se usan como carnada en la pesca del atún . . . y otras clases de peces que pescan las embarcaciones atuneras; y asimismo sobre los efectos de los factores naturales y de la acción del hombre en la abundancia de las poblaciones de peces que sostengan a todas estas pesquerías."

como también

> "Recomendar en su oportunidad, a base de investigaciones científicas, la acción conjunta necesaria . . . para fines de mantener las poblaciones de peces que abarca esta Convención en el nivel de abundancia que permita la pesca máxima constante."

La Comisión inició sus investigaciones, las cuales son conducidas por un personal científico internacional permanente, en 1951.

Existe una disposición en la Convención (Art. V, 3.) por medio de la cual:

> "Todo gobierno cuyos nacionales tomen parte en las operaciones de pesca que abarca esta Convención . . . Al recibir el consentimiento unánime de las Altas Partes Contratantes . . ."

puede adherirse. Bajo esta cláusula la República de Panamá se adhirió en 1953, la República del Ecuador en 1961 y los Estados Unidos Mexicanos en 1964.

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# OCEANOGRAPHIC OBSERVATIONS FROM THE EASTERN PACIFIC OCEAN COLLECTED BY THE R/V *SHOYO MARU,* OCTOBER 1963 - MARCH 1964

by

Eric D. Forsbergh and William W. Broenkow[1]

## INTRODUCTION

The Nankai Regional Fisheries Research Laboratory of Kochi, Japan conducted a long-line fishery exploration and hydrographic survey in the eastern Pacific Ocean aboard the R/V *Shoyo Maru* during October 1963-March 1964. An invitation to the Inter-American Tropical Tuna Commission to participate in the cruise gave its investigators the opportunity to make surface biological observations and to preserve water samples for subsequent analyses of nutrients. The result of this survey is a comprehensive body of physical, chemical and biological data covering a large portion of the eastern half of the Pacific Ocean.

The Nankai Laboratory has generously allowed the Tuna Commission to publish all oceanographic results. By incorporating the results of the two agencies into one report, the data will be readily accessible for detailed study. A complete listing of data is given in the Appendices. Observed values of temperature, chlorinity, oxygen, weather, sea state, water transparency and zooplankton volumes have also been presented by the Japan Ministry of Agriculture and Forestry, Fishing Agency, Investigation Research Division, First Research Section (1964).

No attempt has been made to give extensive interpretations of these data, but some features of general interest have been described briefly. It is hoped that this report will complement previous descriptive studies of the eastern tropical Pacific Ocean such as those by Wooster and Cromwell (1958) and Bennett (1963).

## SCIENTIFIC PERSONNEL

The following scientific personnel participated in Cruise 13 of the R/V *Shoyo Maru:*

| | |
|---|---|
| Dr. Yoichi Yabuta<br>Chief Investigator | Japan Fisheries Agency, Nankai Regional Fisheries Research Laboratory |
| Mr. Kozo Nagai | Japan Fisheries Agency, Second Deep Sea Section |
| Mr. Keiichiro Mori | Japan Fisheries Agency, Nankai Regional Fisheries Research Laboratory |
| Mr. Izumi Nakamura | Kyoto University, Department of Fisheries |

---

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| Mr. Witold L. Klawe | Inter-American Tropical Tuna Commission |
| Mr. Eric D. Forsbergh | Inter-American Tropical Tuna Commission |

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The U. S. Bureau of Commercial Fisheries, Tuna Resources Laboratory, La Jolla, California assisted in the analyses of samples ashore.

## METHODS

In addition to long-line fishing operations, investigators of the Nankai Laboratory made hydrographic casts, chlorinity titrations, oxygen analyses, larval net tows, weather observations and bathythermograph and Secchi disc lowerings. Tuna Commission scientists preserved water samples for the analyses of nutrients and plant pigments and conducted carbon fixation experiments aboard ship. The nutrient and pigment analyses were made ashore by staff members of the Bureau of Commercial Fisheries and the Tuna Commission.

### Station spacing

Because the primary purpose of the survey was fishery research, hydrographic stations were spaced farther apart than might have been planned for a solely oceanographic survey. Hydrographic stations were planned to be about 120 to 160 miles apart, with two surface stations and bathythermograph casts between. The bathythermograph became inoperative at station H-89 (Fig. 1) and, to offset this loss of data, hydrographic stations from H-89 to H-153 were made at approximately 60-mile intervals. After station H-153, the original spacing of hydrographic stations was resumed, because replacement of the bathythermograph made such observations again possible.

### Depth

Two Nansen bottle casts were made at each hydrographic station. For the first cast the bottles were lowered to nominal depths of 25, 50, 75, 100 and 150 m, and actual sampling depths were determined by wire angle. The second cast to nominal depths of 200, 300, 400 and 600 m utilized unprotected reversing thermometers, and the actual depth of sampling was determined thermometrically. Surface samples were collected with a bucket.

### Temperature

Subsurface temperatures were determined with a single protected reversing thermometer on each Nansen bottle. Bathythermograph lowerings were made to about 200 m at each hydrographic station and frequently between stations. Surface temperatures were determined by bucket thermometer. The precision of the single reversing thermometer readings is about ±0.04 C (Wooster and Taft, 1958).

### Chlorinity

Chlorinity determinations were made aboard ship by the standard silver nitrate titration using fluorescein as the indicator. Precision of the analyses was about ±0.03‰ Cl, or about ±0.06‰ S (Strickland and Parsons, 1960).

### Dissolved-oxygen

Dissolved-oxygen analyses were performed aboard ship using the Winkler sodium thiosulfate titration. Precision of the method is about ±0.03 ml/L (Strickland and Parsons, 1960).

### Nutrients

Immediately after the hydrographic stations were completed, 250-ml sea water samples were drawn from the Nansen bottles into polyethylene bags, which were placed into protective outer bags and then frozen. The samples were stored at −10 to −15 C for shipment to San Diego, California for analyses. Maximum storage time was 24 weeks. The effect of freezing on the accuracy of the determinations was not ascertained, but Stefansson and Richards (1963) have shown that the agreement between samples analyzed fresh and those analyzed after frozen storage is good (their samples for phosphate were stored for 4 weeks, those for nitrate for 2 weeks, and those for silicate for 10 weeks).

In the laboratory, the samples were thawed overnight at room temperature. They were filtered through Whatman Number 42 filter paper and were analyzed using methods described by Strickland and Parsons (1960): for inorganic nitrite-nitrogen, using sulfanilamide and N-(1-naphthyl)-ethylene-diamine for color development; for inorganic nitrate-nitrogen, by reduction with hydrazine and subsequent analysis for nitrite; and for reactive silicate-silicon, using metol-sulfite and oxalic acid to reduce the silicomolybdate complex. Analyses of inorganic phosphate-phosphorus were made by the ascorbic acid, potassium antimony tartrate method of J. P. Riley as described by J. D. H. Strickland and T. R. Parsons (*unpublished*). The precisions of the analyses were: phosphate, ±0.03 $\mu$g-at/L; nitrate, ±0.3 $\mu$g-at/L at the 4.5 $\mu$g-at/L level and ±1.3 $\mu$g-at/L at the 30 $\mu$g-at/L level; nitrite, ±0.03 $\mu$g-at/L; silicate, ±0.25 $\mu$g-at/L at the 10 $\mu$g-at/L level and ±1.4 $\mu$g-at/L at the 60 $\mu$g-at/L level (from Strickland and Parsons, 1960 and *unpublished*).

### Plant pigments

Samples of surface water were collected with a bucket, magnesium carbonate was added and the samples were filtered immediately through Whatman GF/C glass filters. During filtration suction was maintained at pressures between 25 and 35 cm of mercury. The filters were desiccated under vacuum in the dark. The samples were maintained dry, dark and frozen for up to 6 weeks before analysis, the maximum period considered allowable for such storage by Parsons and Strickland (1960). Analyses for plant pigments were made in San Diego by the Richards with Thompson (1952) method. Concentrations were computed using the equations of Parsons and Strickland (1963). Precisions of the analysis are from J. D. H. Strickland and T. R. Parsons (*unpublished*): chlorophyll *a*, ±0.05 mg/m$^3$ at the 1 mg/m$^3$ level; chlorophyll *b*, ±0.04 mg/m$^3$ at the 0.1 mg/m$^3$ level; plant carotenoids, ±0.03 mSPU at the 0.3 mSPU level. Chlorophyll *c* determinations are inaccurate and unprecise.

On 28 occasions samples were simultaneously filtered through Whatman GF/C filters with Millipore HA filters beneath. This was done to determine the amount of phytoplankton which was retained by the glass filter compared to that which was retained by the Millipore filter. On the average, 80% (with a range of 64% to 96%) of the phytoplankton was retained by the glass filter as indicated by measurements of optical density at 665 m$\mu$. To compensate for loss through the glass filters, all pigment values were therefore multiplied by a factor of 1.25.

From station H-26 through station H-153 the pigments were extracted for 18 hours; from station H-154 through station P-98 the glass filters and phytoplankton were ground in a tissue grinder by the method of Yentsch and Menzel (1963), and the pigments were extracted for 2 hours. The relationship between carbon fixation and chlorophyll *a* as determined by the two extraction methods was essentially the same. Thus it appears that in this case the two methods of extracting the pigments gave similar results.

### Carbon fixation

The rate of carbon fixation by surface phytoplankton was measured by the radiocarbon (carbon$^{14}$) method of Steemann Nielsen (1952). Samples of surface water were collected with a polyethylene bucket. They were incubated at sea-surface temperature under natural light between sunrise and noon or between noon and sunset. Procedures for standardization, counting and the calculations are identical with those given by Forsbergh and Joseph (1964). The same radiocarbon solution was used throughout the cruise. Twenty mCof radioactivity were added to each sample. The precision at the 15 mgC/m$^3$ day level was ±1.5 mgC/m$^3$ day (from Strickland and Parsons, 1960).

### Zooplankton

Description of larval nets and procedures are given by Japan Ministry of Agriculture and Forestry, Fishery Agency (1964). The surface net was 1.4 m in diameter and was towed 10 minutes at about 2 knots. The subsurface net was 2.0 m in diameter and was towed 10 minutes at the same speed at about 20 m depth. Volumes of wet zooplankton which were collected by the larval nets were measured by displacement. Volumes of organisms longer than 5 cm were measured separately.

Griffiths (1963), using total variance, has shown that the 95% confidence limits of a single oblique zooplankton tow are ⅓ and 3 times the value for the tow, which probably approximate the confidence limits of horizontal tows.

## TREATMENT OF DATA

All data computations and interpolations were processed by a Control Data Corporation 3600 computer (see Appendix D for program methods). At observed depths, density was determined from observed temperature and chlorinity. Both temperature and density values were interpolated at standard depths by two-point logarithmic interpolation. Salinity values at standard depths were computed from these interpolated values of temperature and density.

Only observed oceanographic variables have been illustrated in this report. Computed properties such as the interpolated values, density, transport function and apparent oxygen utilization have not been used.

Sections were drawn so that the distributions of all variables were consistent with one another. Anomalous data points were eliminated on the basis of inconsistencies between the distributions of different properties. These apparently erroneous results have been noted in the data listings. Isopleths were drawn by linear interpolation except in the case of temperature where bathythermograph data were available (Sections I, VII, VIII and IX). In these instances the bathythermograph sections were drawn first, and the isotherms between hydrographic stations then drawn in accordance with the bathythermograph data.

Sections were drawn with a linear scale for either latitude or longitude. The vertical exaggerations of the sections vary, because they are oriented at different angles to the meridian. The approximate vertical exaggerations are:

| | | | |
|---|---|---|---|
| Section I | 6,700:1 | Section VI | 7,600:1 |
| Section II | 10,900:1 | Section VII | 8,400:1 |
| Section III | 9,300:1 | Section VIII | 5,700:1 |
| Section IV | 10,800:1 | Section IX | 8,000:1 |
| Section V | 5,800:1 | Section X | 6,800:1 |

Because samples for pigment determinations were taken at different times of the day, an attempt was made to detect diurnal periodicity in pigment concentrations. Concentrations of chlorophyll *a* were grouped by time of collection. Median and rank tests showed no significant difference in chlorophyll *a* concentrations between time groups. The data were therefore not corrected for time of collection.

Distributions of surface chlorophyll *a* corresponding to the physical and chemical sections are shown by line graphs because observations were too close together to be shown as bar graphs. Values for cholorophyll *a* and carbon fixation are shown on logarithmic scales for ease of reading.

The areal distributions of the biological variables were constructed from running means of values at consecutive stations to eliminate some of the variation owing to patchiness and to the low precision of the methods. The number of observations used in each of the running means was selected so that comparable distances were represented by each of the means. Because observations on carbon-fixation were far apart, individual values were used. The areal distribution of chlorophyll *a* (Fig. 7a) is represented by running means of values from 5 consecutive stations.

To construct the areal distribution of zooplankton volume (Fig. 7c), factors were computed to correct for differences in zooplankton volume owing to diurnal migration, depth dependence and size of sampling net. The net tows can be divided into four types: a) surface tows during the night, b) surface tows during the day, c) 20-m tows during the night, and d) 20-m tows during the day. The volumes collected by these tows were compared at individual stations and between adjacent stations. The median values of ratios for each comparison were used as factors to determine volumes equivalent to surface tows during the night:

| | |
|---|---|
| Surface tows during the day | 4.0 |
| 20-m tows during the night | 0.2 |
| 20-m tows during the day | 0.5 |

The areal distribution of zooplankton is shown by running means of these corrected volumes for three consecutive stations.

The areal distribution of water transparency (Fig. 7d) is represented by running means of Secchi disc depths for three consecutive stations.

## FEATURES OF INTEREST

Strong horizontal gradients dominate the distributions of properties at the southern portions of Sections II and V (Figs. 3, 4). The steeply sloping isotherms, which here are approximately parallel to isopycnals, show the effects of the eastward-flowing west-wind drift between the southern ends of these sections and about 25°S. In these sections at the south, surface Subantarctic Water was cool and of low salinity (13 C, $34^{0}/_{00}$) compared to warm, high-salinity (27 C, $36^{0}/_{00}$) Eastern South Pacific Central Water to the north. Appreciable phosphate and nitrate concentrations and barely detectable silicate concentrations were found near 40°S. Detectable nitrite concentrations were found only in the thermocline, and the amount of nitrite was greatest near 40°S. The productive nature of the Subantarctic Water is demonstrated by relatively high values for chlorophyll *a* and carbon-fixation in the southern portions of these sections.

Evidence of the Peru-Chile Undercurrent (Wooster and Gilmartin, 1961) is seen in both Sections III and IV (Fig. 3) between 200 and 300 m. The eastern portions of these sections show a core of relatively high-salinity, nutrient-rich and oxygen-poor water which is attributed to the southward-flowing undercurrent.

The northern edge of the Peru Current is clearly shown in Sections VI and VII (Figs. 4b; 5b) by the sharp gradient in surface salinity across the equator where high-salinity ($>35^{0}/_{00}$) water from the Peru Current meets low-salinity ($<33^{0}/_{00}$) water from the Panama Bight. The westward extension of the Peru Current affects the surface distribution of properties as shown in Section V (Fig. 4). Surface water with high nutrient concentrations near 10°S probably originated in the upwelling areas near the coast of Peru and Chile and was transported offshore by the Peru Current. These waters had high values of chlorophyll *a* and carbon-fixation. The thermocline in the westward extension of the Peru Current contained particularly high nitrite concentrations.

The dissolved-oxygen content decreased toward the north at all depths as shown in Section V (Fig. 4c). This feature has been noted before and is associated with an east-west oriented, low-oxygen layer in the intermediate water of the eastern tropical Pacific Ocean (Wooster and Cromwell, 1958; Bennett, 1963). There are two such low-oxygen layers in the tropical Pacific; one north of the equator and one south of the equator. The northern one appears to be centered at about 15°N in Section VIII (Fig. 5c) and at about 12°N in Section X. The southern low-oxygen layer is centered near 10°S in Sections V and VI (Fig. 4c) and at 3°S in Section X (Fig. 6c). Both the northern and southern low-oxygen layers are markedly narrower in the west than in the east. East of the Galapagos Islands in Sections VI and VII, the low-oxygen layer is continuous across the equator.

The presence of zonal surface currents is indicated by the temperature structure in Sections I, VIII, IX and X (Figs. 2a, d; 5a, d; 6a, d). The North and South Equatorial Currents cause the isotherms to slope upward toward the equator. These currents appear to be strongest in the western sections (Sections I, X and IX). The North Equatorial Countercurrent causes the isotherms to slope upward toward the north. This countercurrent appears between 3°N and 8°N in Section I, between 4°N and 10°N in both Sections X and IX and between 5°N and 7°N in Section VIII.

Isotherms which slope upward toward the south as shown in Section I (Figs. 2a, d) between 8°S and 10°S, Section XI (Fig. 4a) between 8°S and 10°S, Section VII (Figs. 5a, d) between 7°S and 9°S, Section VIII (Fig. 5d) between 7°S and 9°S and in Section IX (Fig. 6d) between 6°S and 8°S may be taken as evidence of a weak South Equatorial Countercurrent first described by Reid (1959). In Sections VIII and IX this sloping of isotherms is not well defined, and in Section X no such sloping is apparent.

Evidence for the Equatorial Undercurrent or Cromwell Current (Knauss, 1960) is shown by the following features in each section crossing the equator: in Section I, by a weak thermocline (Figs. 2a, d) and a slight trough in oxygen isopleths (Fig. 2c); in Section VI, by a weak thermocline (Fig. 4a), a trough in oxygen isopleths (Fig. 4c), and troughs in phosphate, nitrate, and silicate isopleths (Figs. 4d, e, g); in Section VII, by a weak thermocline (Figs. 5a, d) and a trough in oxygen isopleths (Fig. 5c); in Section VIII by a slightly weak thermocline (Fig. 5d) and a trough in oxygen isopleths (Fig. 5c); and in Sections IX and X, by low surface temperature and a weak thermocline (Fig. 6a, d) and a trough in oxygen isopleths (Fig. 6c). This trough in oxygen isopleths was markedly wider in the east than in the west, a phenomenon which may be associated with mixing caused by shear from the eastward flowing Undercurrent. The center of the Undercurrent, as indicated by the weak thermocline, shoaled from west to east from about 180 m at 180° to about 100 m at 100°W.

From the areal distributions of biological variables (Figs. 7a, b, c), it can be seen that primary production and the relative abundance of phytoplankton and zooplankton are high near the coast of Chile and moderately high near 40°S in Subantarctic Water. Sections II, III and IV (Figs. 3d, e, g) show surface nutrient concentrations to be relatively high in both of these areas. In the central south Pacific, however, primary production and standing crops are very low, which is consistent with low nutrient concentrations in this area (Section II, Fig. 3). In the equatorial zone plankton abundance and primary production are high in the easternmost region and decrease toward the west. Equatorial Sections VII, VIII, IX, X and I (Figs. 5a, d; 6a, d; 2a, d) show the thermocline to be shallow in the east and to deepen toward the west. The high productivity and plankton abundance in the east may be related to rapid replenishment of nutrients facilitated by a shallow thermocline, and to the south and east of the Galapagos Islands it may also be related to nutrient-rich water originating from coastal upwelling. The coincidence of zones of relatively low plankton production and abundance centered at 7°N between 115°W and 100°W (Figs. 7a, b, c) may be related to the North Equatorial Countercurrent located at this latitude (Sections VIII, IX and X). The distribution of Secchi disc depths (Fig. 7d) corresponds to the distributions of the biological variables, with the less transparent water occurring in biologically-rich areas.

# LIST OF FIGURES—LISTA DE LAS FIGURAS

**FIGURE 1.** Track chart and hydrographic station positions. Roman numerals refer to the sections.

**FIGURA 1.** Mapa del derrotero y posiciones de las estaciones hidrográficas. Los números romanos se refieron a las secciones.

**FIGURE 2.** Distributions of properties along Section I (Oct. 6-12, 1963)

**FIGURA 2.** Distribuciones de las propiedades a lo largo de la Sección I (oct. 6-12, 1963)
a) Temperature, contour interval = 2 C
Temperatura, intervalo del contorno = 2 C
b) Salinity, contour interval = 0.2‰
Salinidad, intervalo del contorno = 0.2‰
c) Dissolved oxygen, contour interval = 1.0 ml/L
Oxígeno disuelto, intervalo del contorno = 1.0 ml/L
d) Bathythermograph temperature, contour interval = 2 C
Temperatura batitermográfica, intervalo del contorno = 2 C

**FIGURE 3.** Distributions of properties along Sections II (Oct. 18-Nov. 15, 1963), III (Nov. 16-23, 1963), and IV (Dec. 5-8, 1963).

**FIGURA 3.** Distribuciones de las propiedades a lo largo de las Secciones II (oct. 18-nov. 15, 1963), III (nov. 16-23, 1963), y IV (dic. 5-8, 1963).
a) Temperature, contour interval = 2 C
Temperature,intervalo del contorno = 2 C
b) Salinity, contour interval = 0.2‰
Salinidad, intervalo del contorno = 0.2‰
c) Dissolved oxygen, contour interval = 1.0 ml/L
Oxígeno disuelto, intervalo del contorno = 1.0 ml/L
d) Inorganic phosphate-phosphorus, contour interval = 0.4 $\mu$g-at/L
Fósforo inorgánico en forma de fosfato, intervalo del contorno = 0.4 $\mu$g-at/L
e) Inorganic nitrate-nitrogen, contour interval = 5 $\mu$g-at/L
Nitrógeno inorgánico en forma de nitrato, intervalo del contorno = 5 $\mu$g-at/L
f) Inorganic nitrite-nitrogen, contour interval = 0.2 $\mu$g-at/L
Nitrógeno inorgánico en forma de nitrito, intervalo del contorno = 0.2 $\mu$g-at/L
g) Reactive silicate-silicon, contour interval = 5 $\mu$g-at/L
Silicio reactivo en forma de silicato, intervalo del contorno = 5 $\mu$g-at/L
h) Surface distributions of chlorophyll *a*, mg/$m^3$ and carbon fixation, mg/$m^3$day
Distribuciones en la superficie de la clorofila *a*, mg/$m^3$ y fijación del carbono, mg/$m^3$día

**FIGURE 4.** Distributions of properties along Sections V (Dec. 8-21, 1963) and VI (Dec. 21-26, 1963)

**FIGURA 4.** Distribuciones de las propiedades a lo largo de las Secciones V (dic. 8-21, 1963) y VI (dic. 21-26, 1963)
a) Temperature, contour interval = 2 C
Temperatura, intervalo del contorno = 2 C
b) Salinity, contour interval = 0.2‰
Salinidad, intervalo del contorno = 0.2‰
c) Dissolved oxygen, contour interval = 1.0 ml/L
Oxígeno disuelto, intervalo del contorno = 1.0 ml/L
d) Inorganic phosphate-phosphorus, contour interval = 0.4 $\mu$g-at/L
Fósforo inorgánico en forma de fosfato, intervalo del contorno = 0.4 $\mu$g-at/L
e) Inorganic nitrate-nitrogen, contour interval = 5 $\mu$g-at/L
Nitrógeno inorgánico en forma de nitrato, intervalo del contorno = 5 $\mu$g-at/L
f) Inorganic nitrite-nitrogen, contour interval = 0.2 $\mu$g-at/L
Nitrógeno inorgánico en forma de nitrito, intervalo del contorno = 0.2 $\mu$g-at/L

g) Reactive silicate-silicon, contour interval = 0.2 $\mu$g-at/L
Silicio reactivo en forma de silicato, intervalo del contorno = 0.2 $\mu$g-at/L
h) Surface distributions of chlorophyll *a*, mg/$m^3$ and carbon fixation, mg/$m^3$day
Distribuciones en la superficie de la clorofila *a*, mg/$m^3$ y fijación del carbono, mg/$m^3$día

FIGURE 5. Distributions of properties along Sections VII (Jan. 4-10, 1964) and VIII (Jan. 10-22, 1964)

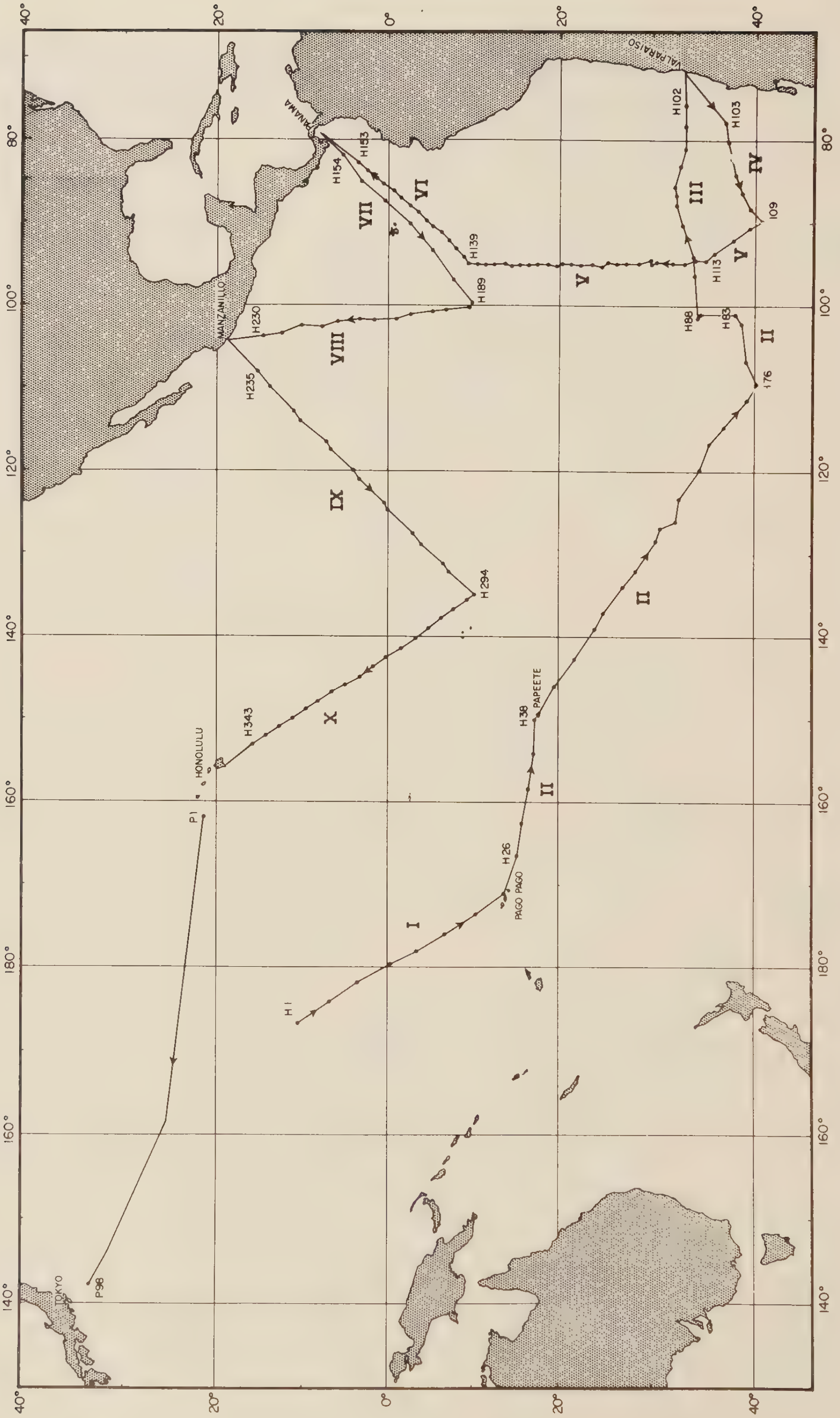
FIGURA 5. Distribuciones de las propiedades a lo largo de las Secciones VII (enero 4-10, 1964) y VIII (enero 10-22, 1964)
a) Temperature, contour interval = 2 C
Temperatura, intervalo del contorno = 2 C
b) Salinity, contour interval = 0.2‰
Salinidad, intervalo del contorno = 0.2‰
c) Dissolved oxygen, contour interval = 1.0 ml/L
Oxígeno disuelto, intervalo del contorno = 1.0 ml/L
d) Bathythermograph temperature, contour interval = 2 C
Temperatura batitermográfica, intervalo del contorno = 2 C
e) Surface distributions of chlorophyll *a*, mg/$m^3$ and carbon fixation, mg/$m^3$day
Distribuciones en la superficie de la clorofila *a*, mg/$m^3$ y fijación del carbono, mg/$m^3$día

FIGURE 6. Distributions of properties along Sections IX (Jan. 31-Feb. 14, 1964) and X (Feb. 14-23, 1964)

FIGURA 6. Distribuciones de las propiedades a lo largo de las Secciones X (enero 31-feb. 14, 1964) y X (feb. 14-23, 1964)
a) Temperature, contour interval = 2 C
Temperatura, intervalo del contorno = 2 C
b) Salinity, contour interval = 0.2‰
Salinidad, intervalo del contorno = 0.2‰
c) Dissolved oxygen, contour interval = 1.0 ml/L
Oxígeno disuelto, intervalo del contorno = 1.0 ml/L
d) Bathythermograph temperature, contour interval = 2 C
Temperatura batitermográfica, intervalo del contorno = 2 C
e) Surface distributions of chlorophyll *a*, mg/$m^3$ and carbon fixation, mg/$m^3$day
Distribuciones en la superficie de la clorofila *a*, mg/$m^3$ y fijación del carbono, mg/$m^3$día

FIGURE 7. Distributions of biological properties at the surface and water transparency.

FIGURA 7. Distribuciones de las propiedades biológicas en la superficie y transparencia del agua.
a) Chlorophyll *a*, mg/$m^3$
Clorofila *a*, mg/$m^3$
b) Carbon fixation, mg/$m^3$day
Fijación del carbono, mg/$m^3$día
c) Zooplankton volume (organisms less than 5 cm long only), ml/net tow
Volumen del zooplancton (solamente organismos de menos de 5 cm de largo), ml por arrastre
d) Secchi disc depth, m
Profundidad del disco Secchi, m



40°
20°
0°
20°
40°
80°
100°
120°
140°
160°
180°
160°
140°
PANAMA
VALPARAISO
MANZANILLO
HONOLULU
PAPEETE
PAGO PAGO
TOKYO
H1
H26
H38
H83
H88
H102
H103
109
H113
H139
H153
H154
H189
H230
H235
H294
H343
176
P1
P98
I
II
III
IV
V
VI
VII
VIII
IX
X

FIGURE 1 — FIGURA 1

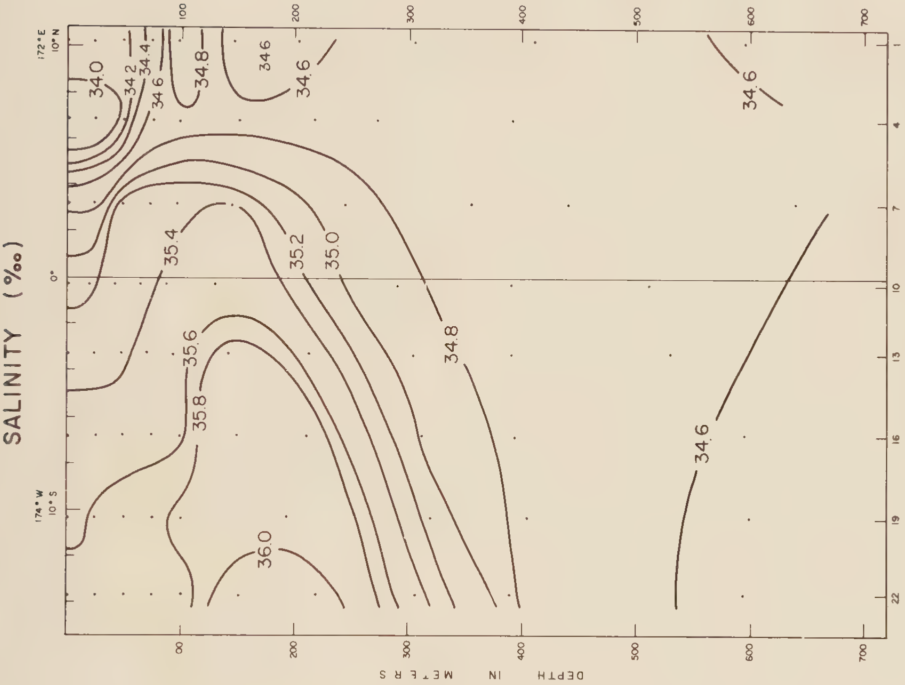


FIGURE 2b — FIGURA 2b

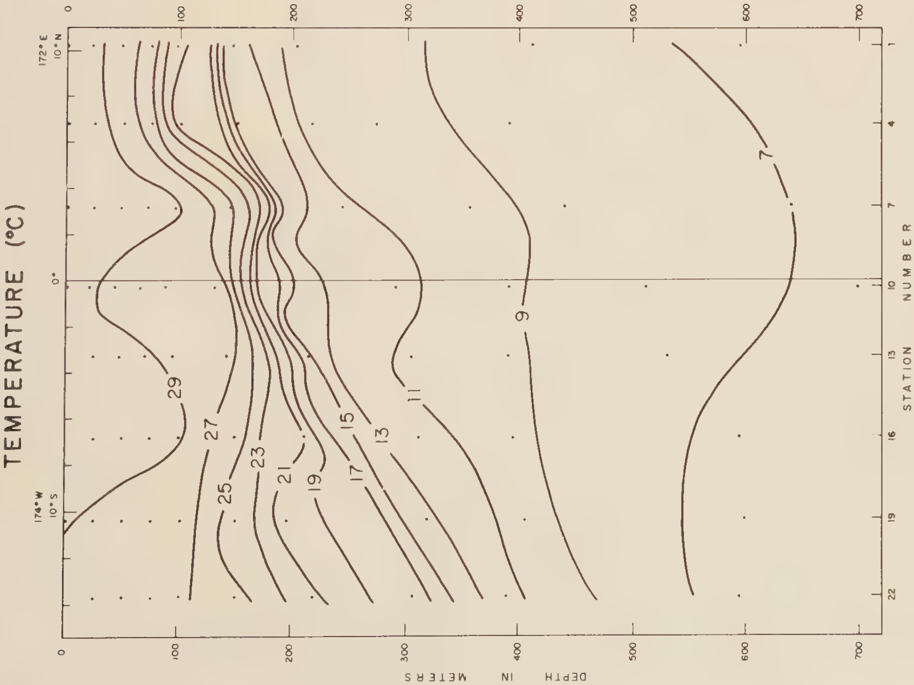


FIGURE 2a — FIGURA 2a

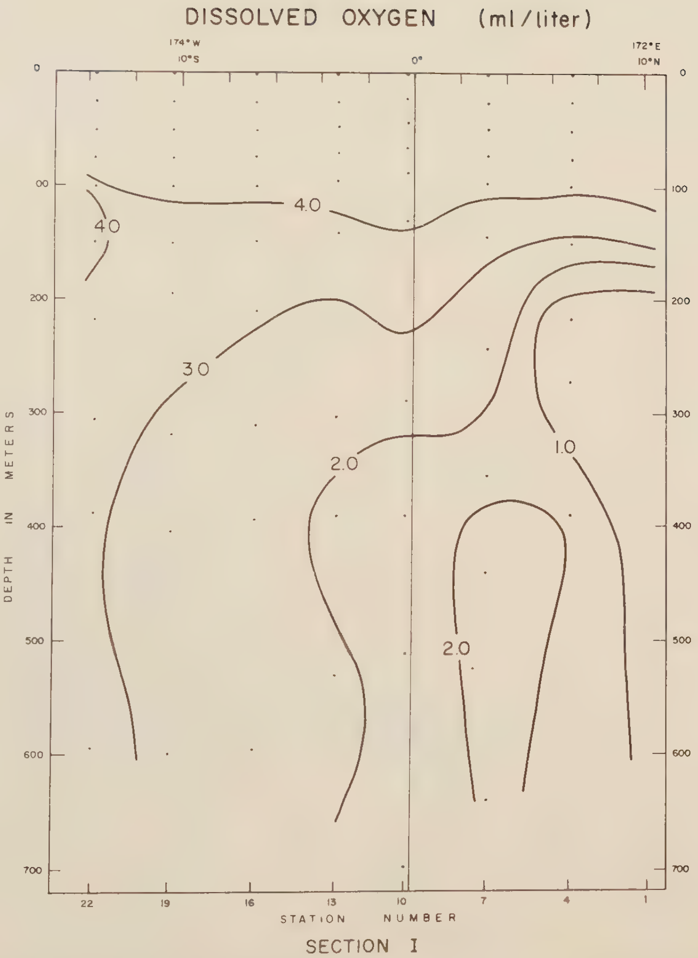


FIGURE 2c — FIGURA 2c

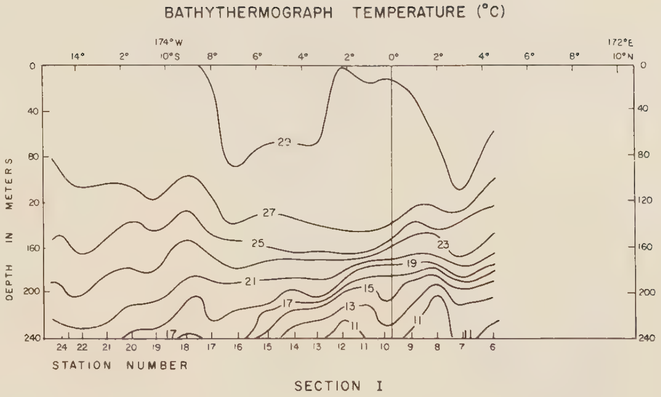


FIGURE 2d — FIGURA 2d

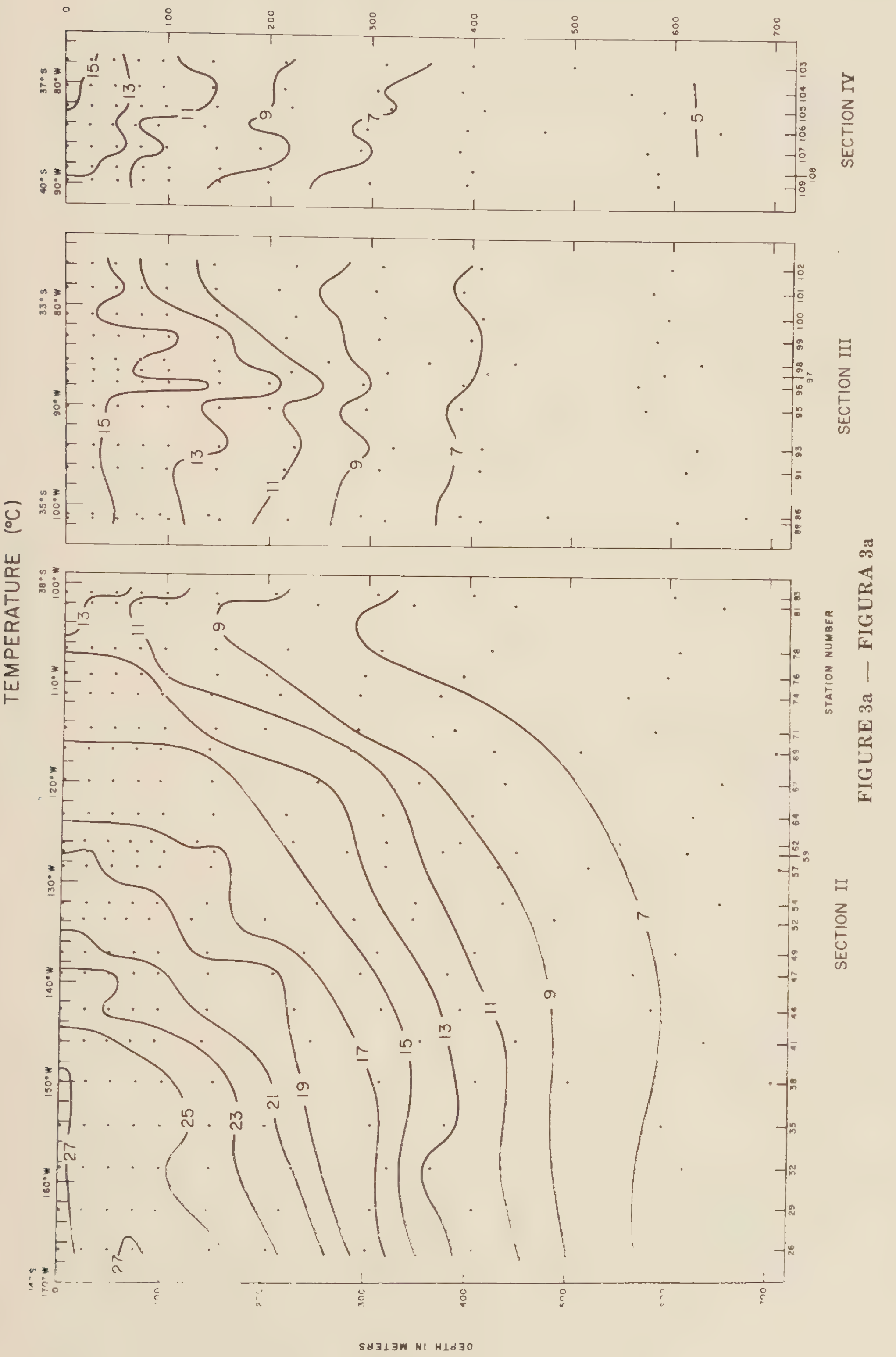


FIGURE 3a — FIGURA 3a

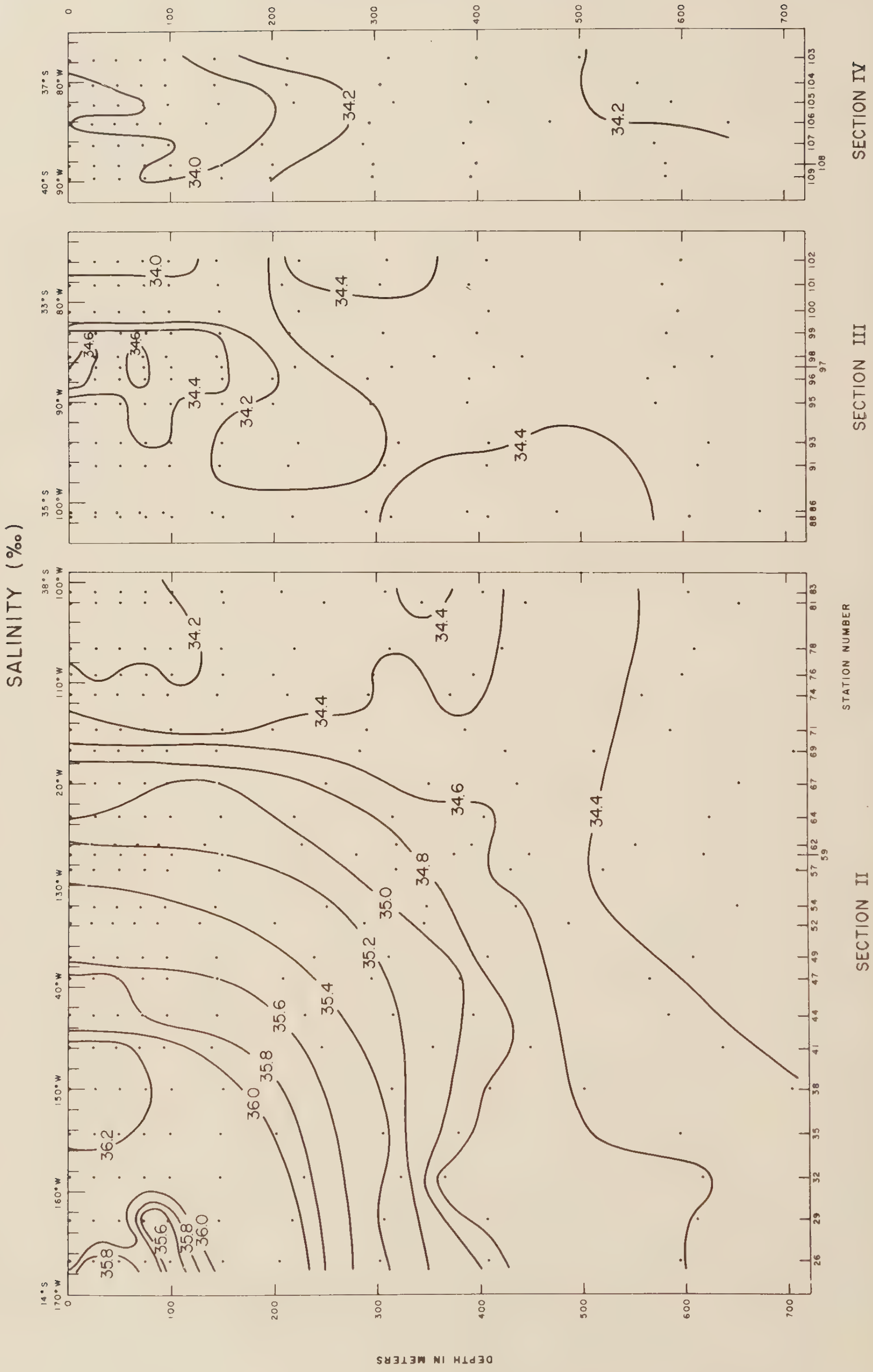
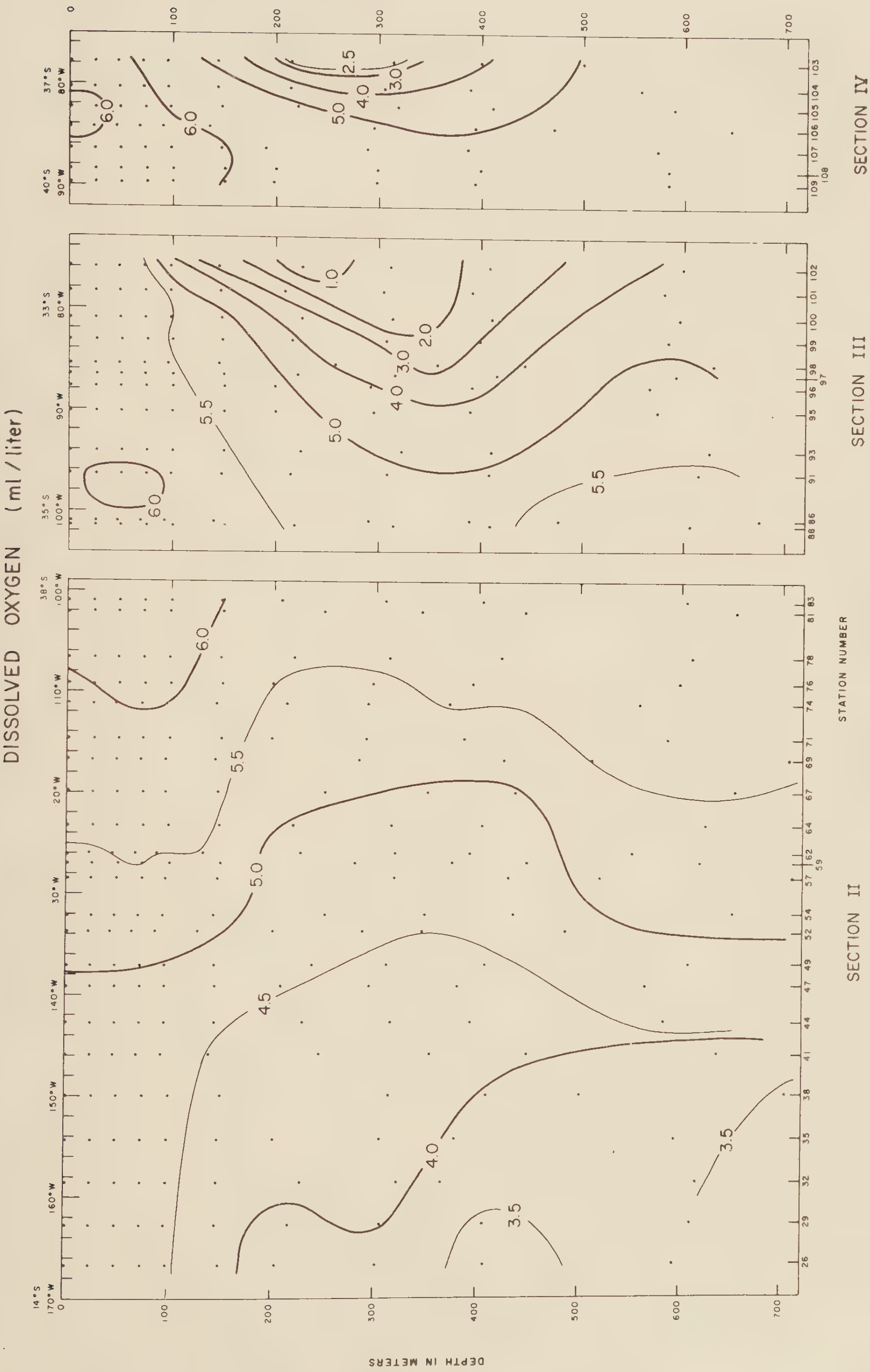


FIGURE 3b — FIGURA 3b



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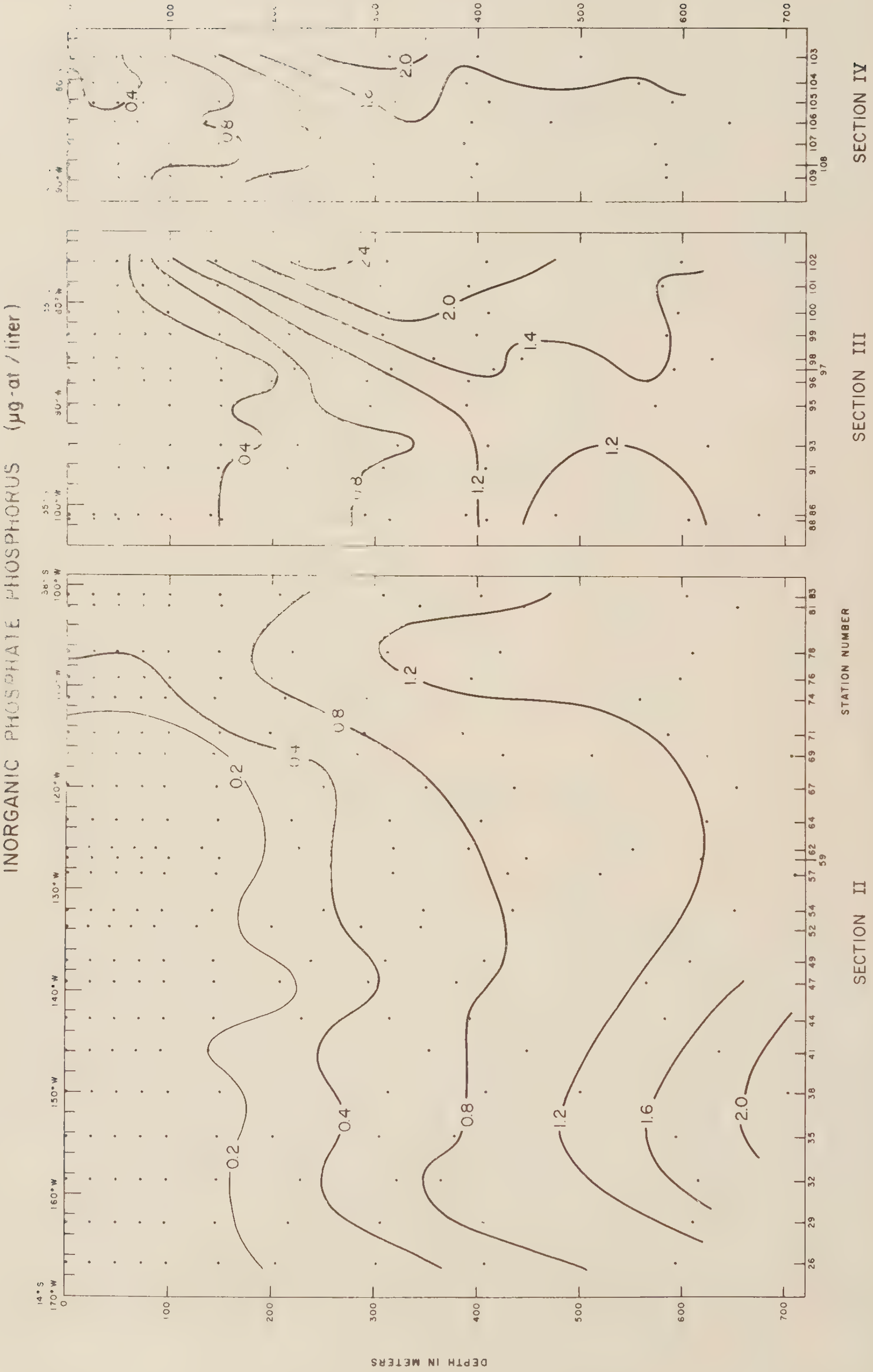

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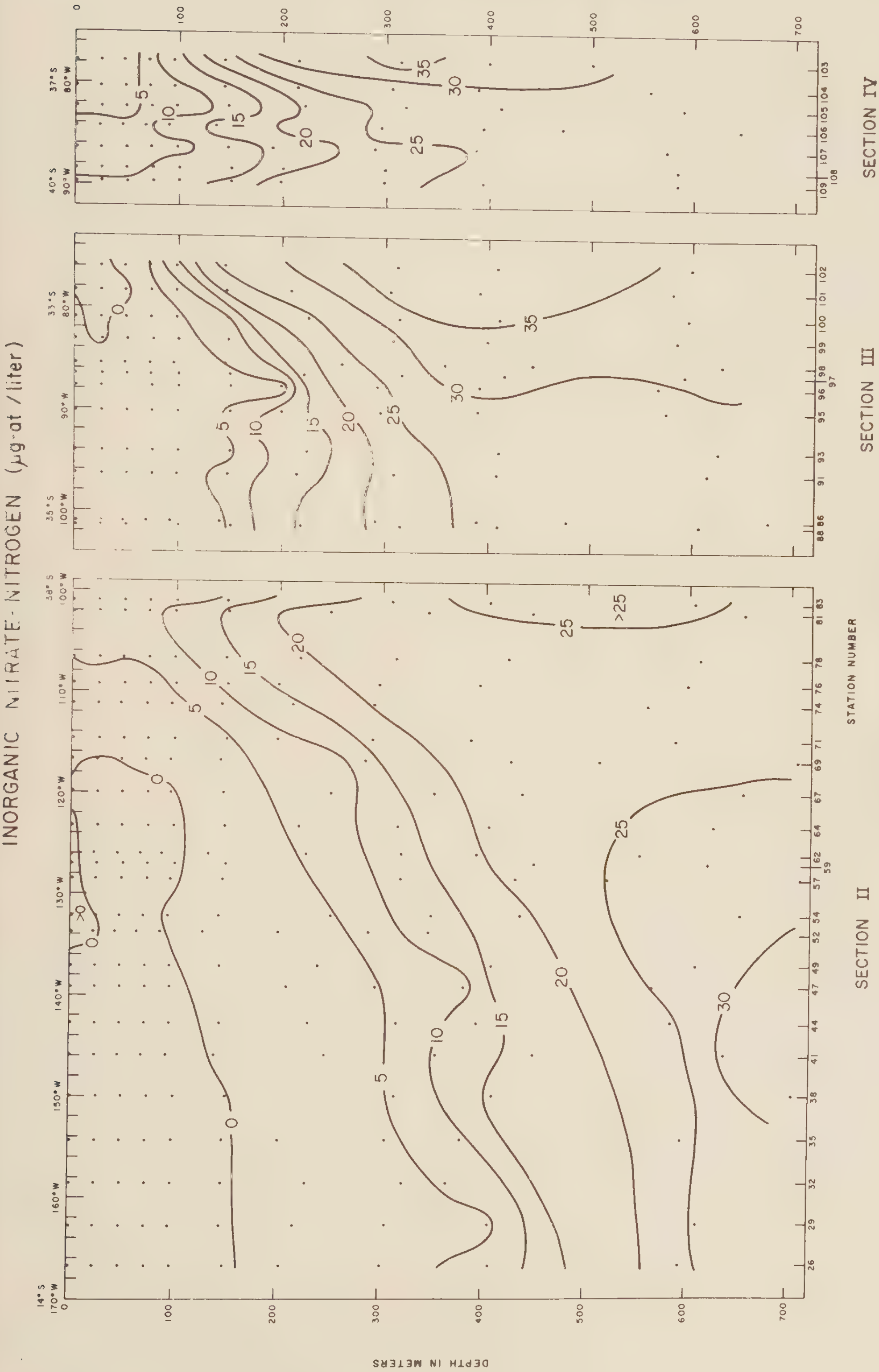

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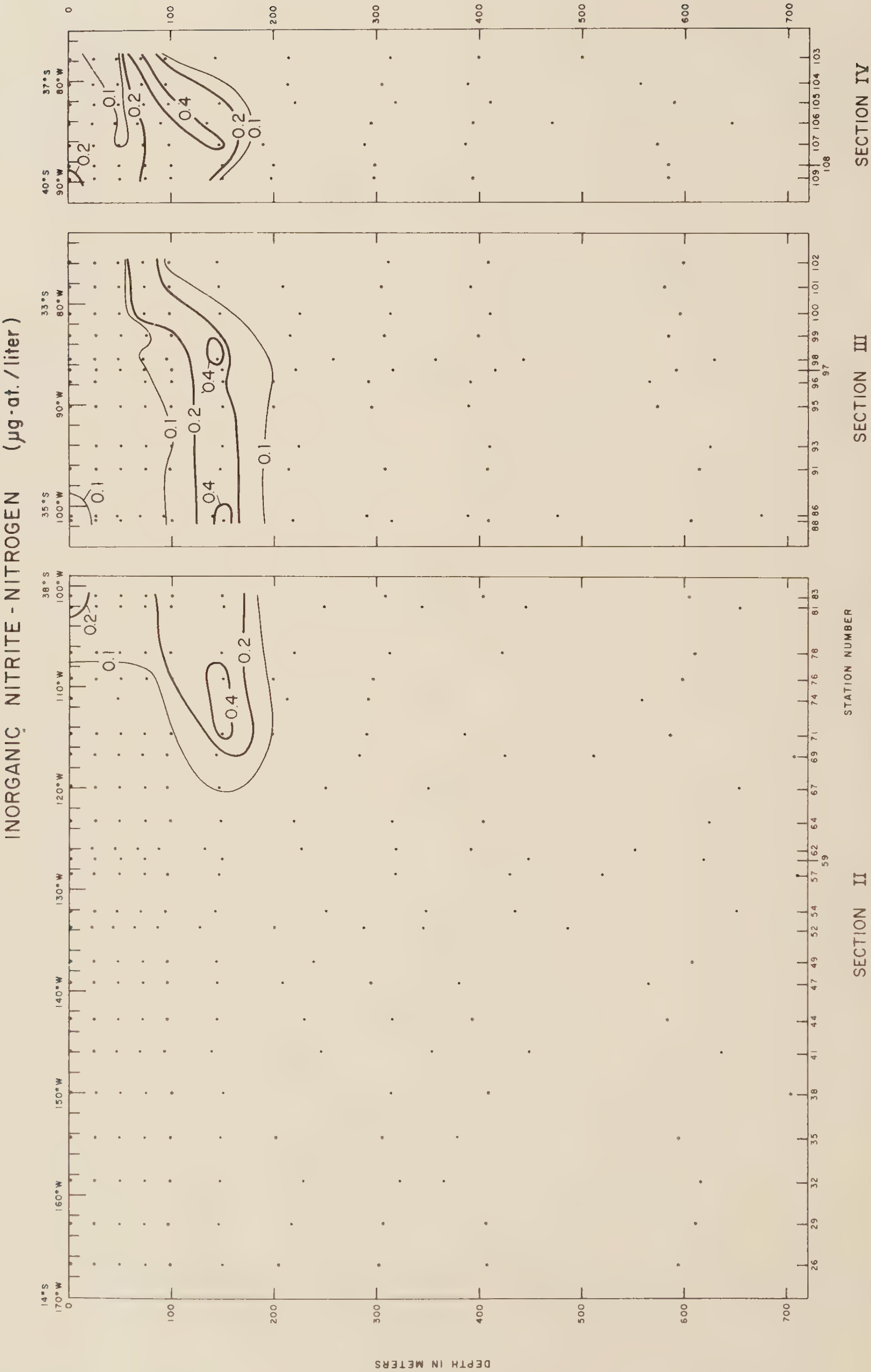

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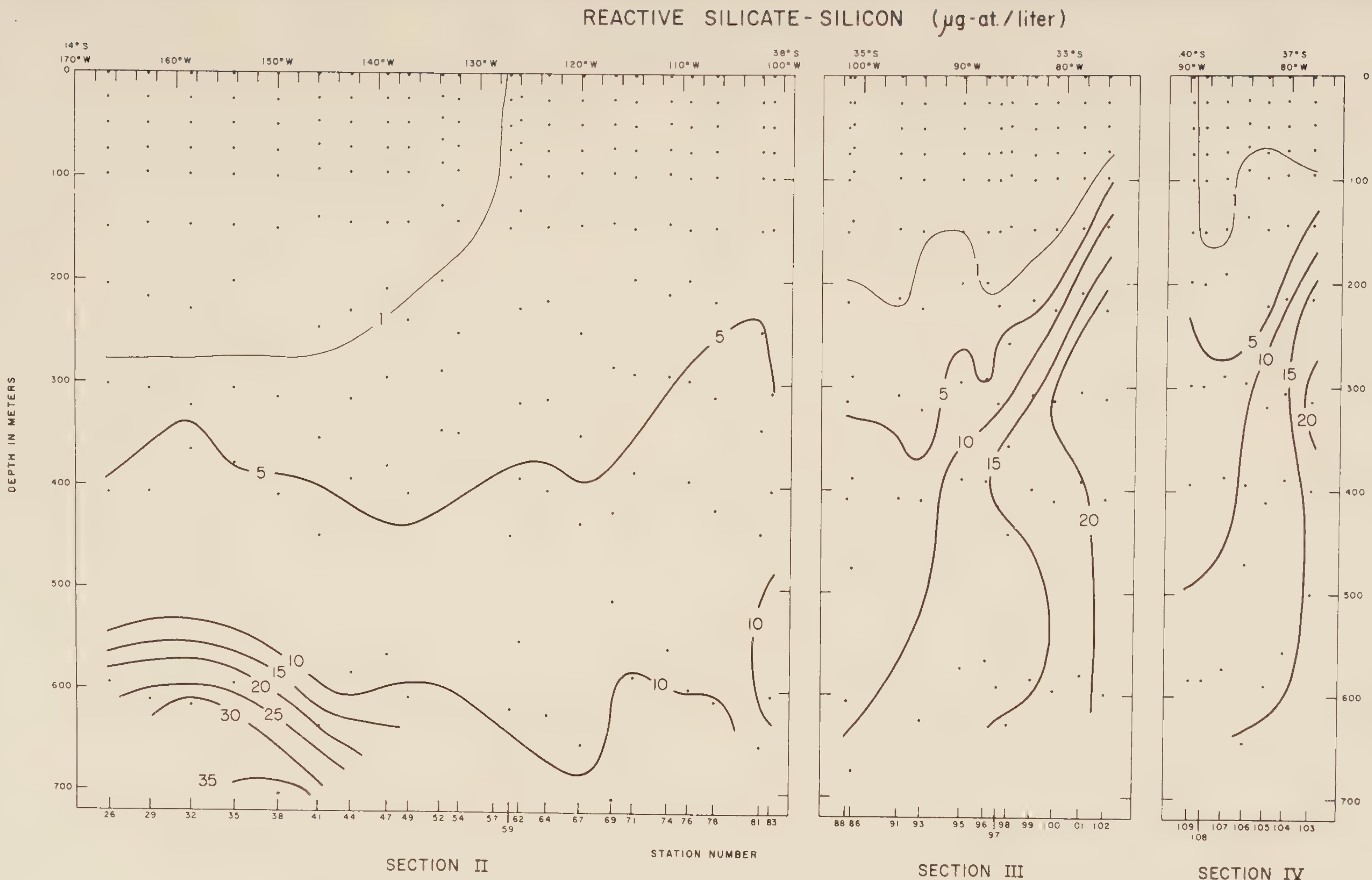


FIGURE 3g — FIGURA 3g

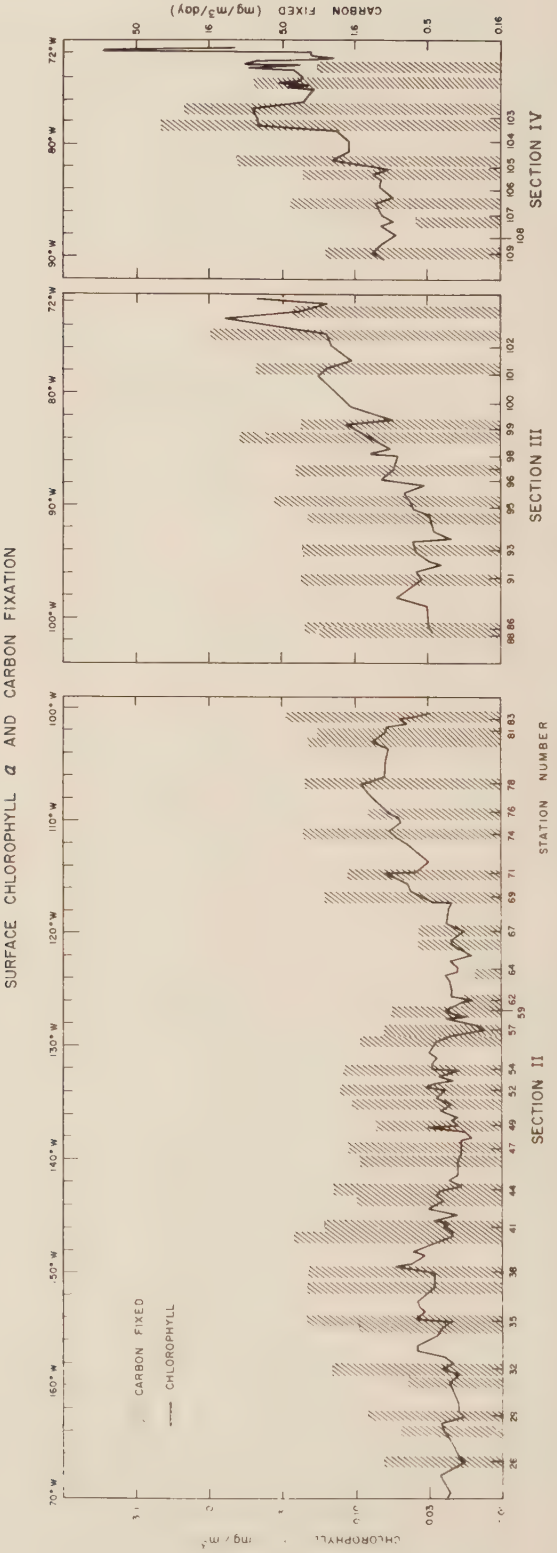


**FIGURE 3h — FIGURA 3h**

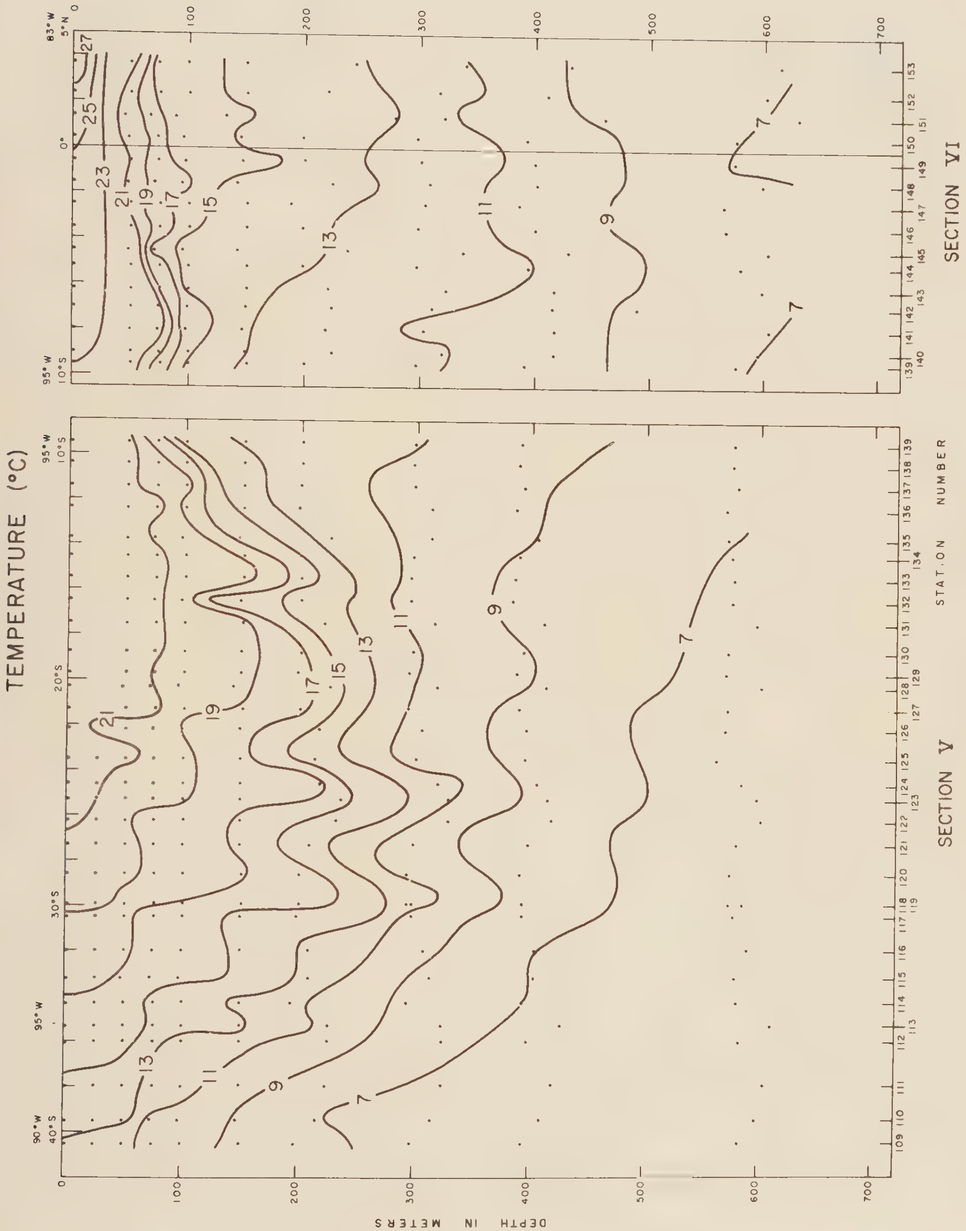


FIGURE 4a — FIGURA 4a

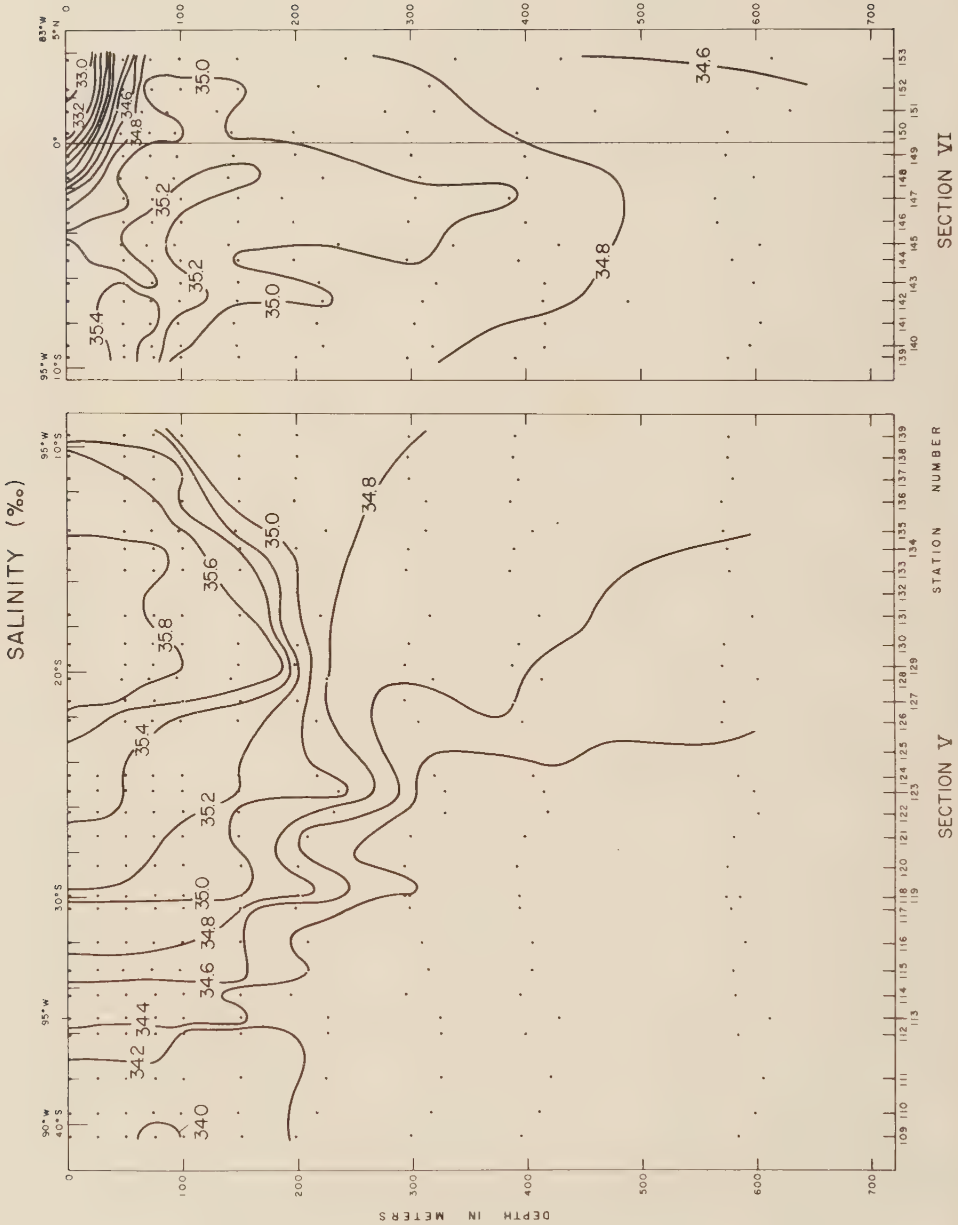
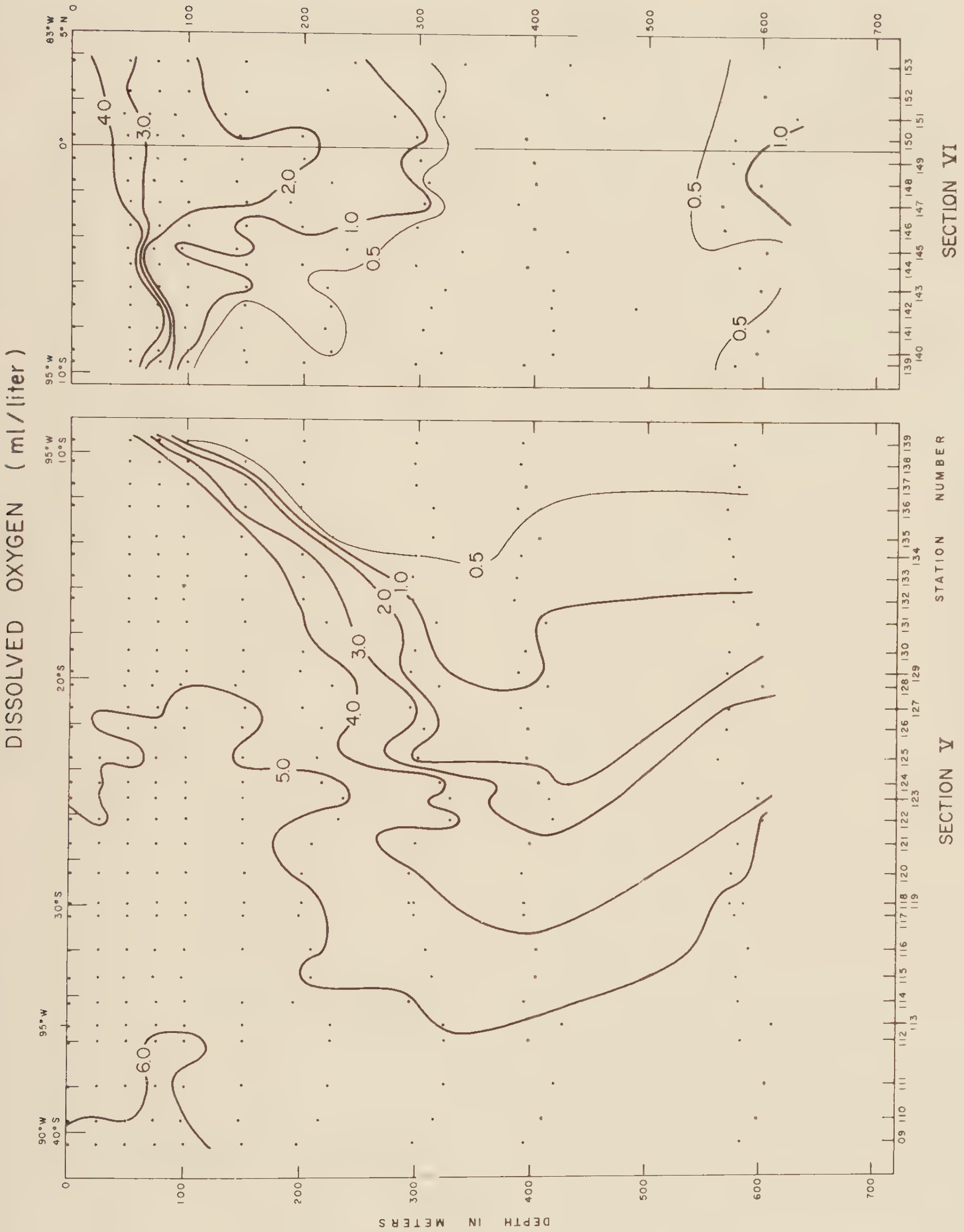


FIGURE 4b — FIGURA 4b



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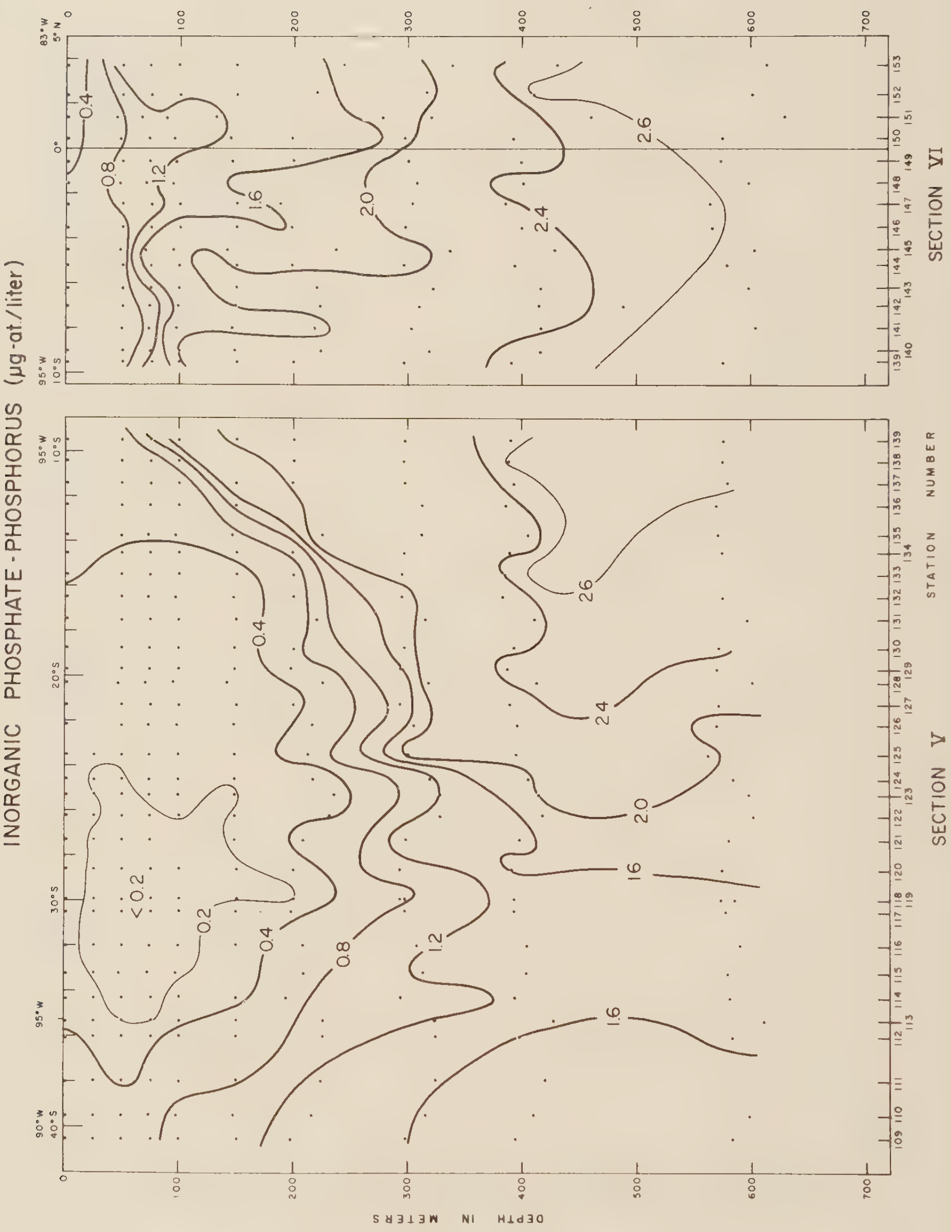

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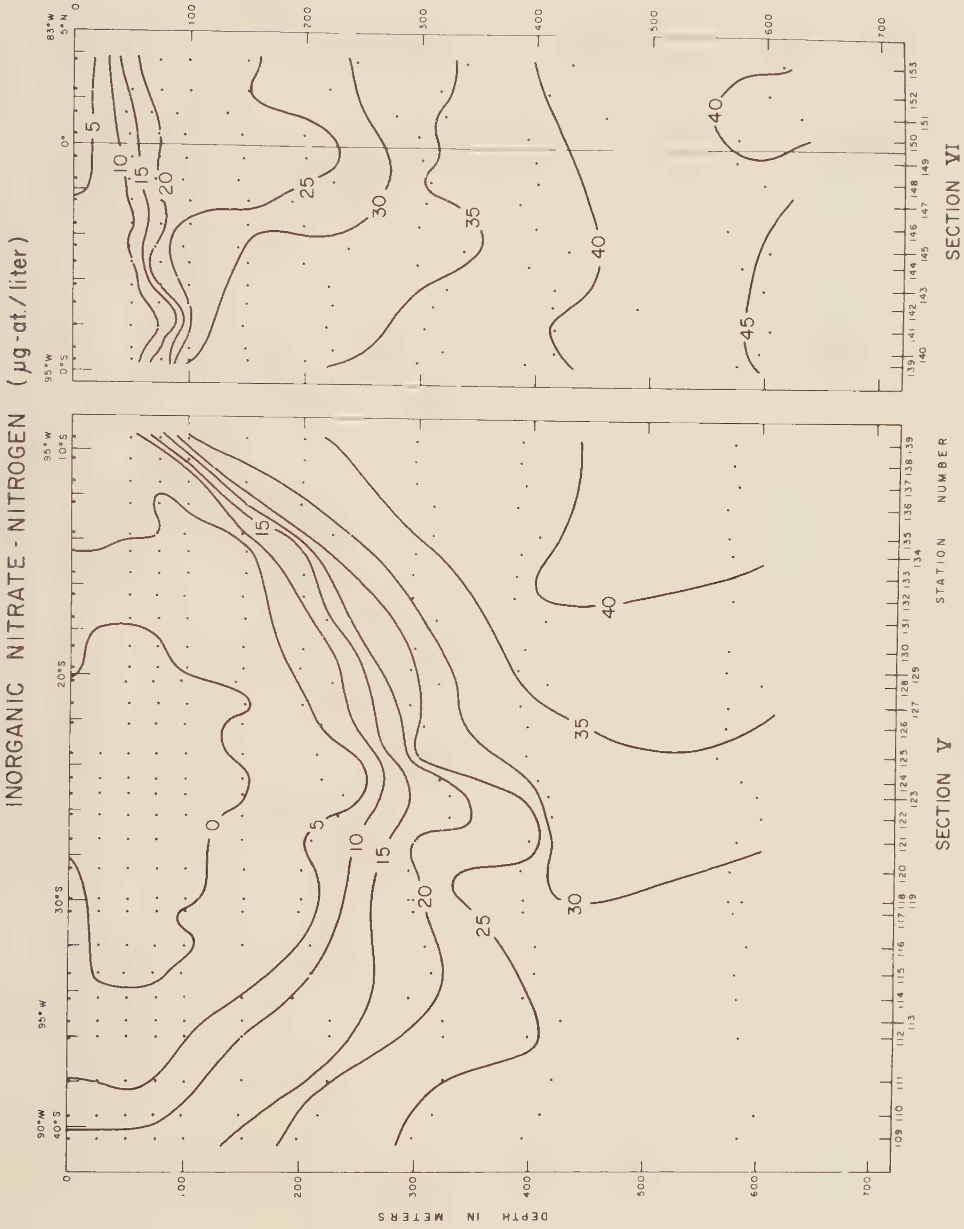

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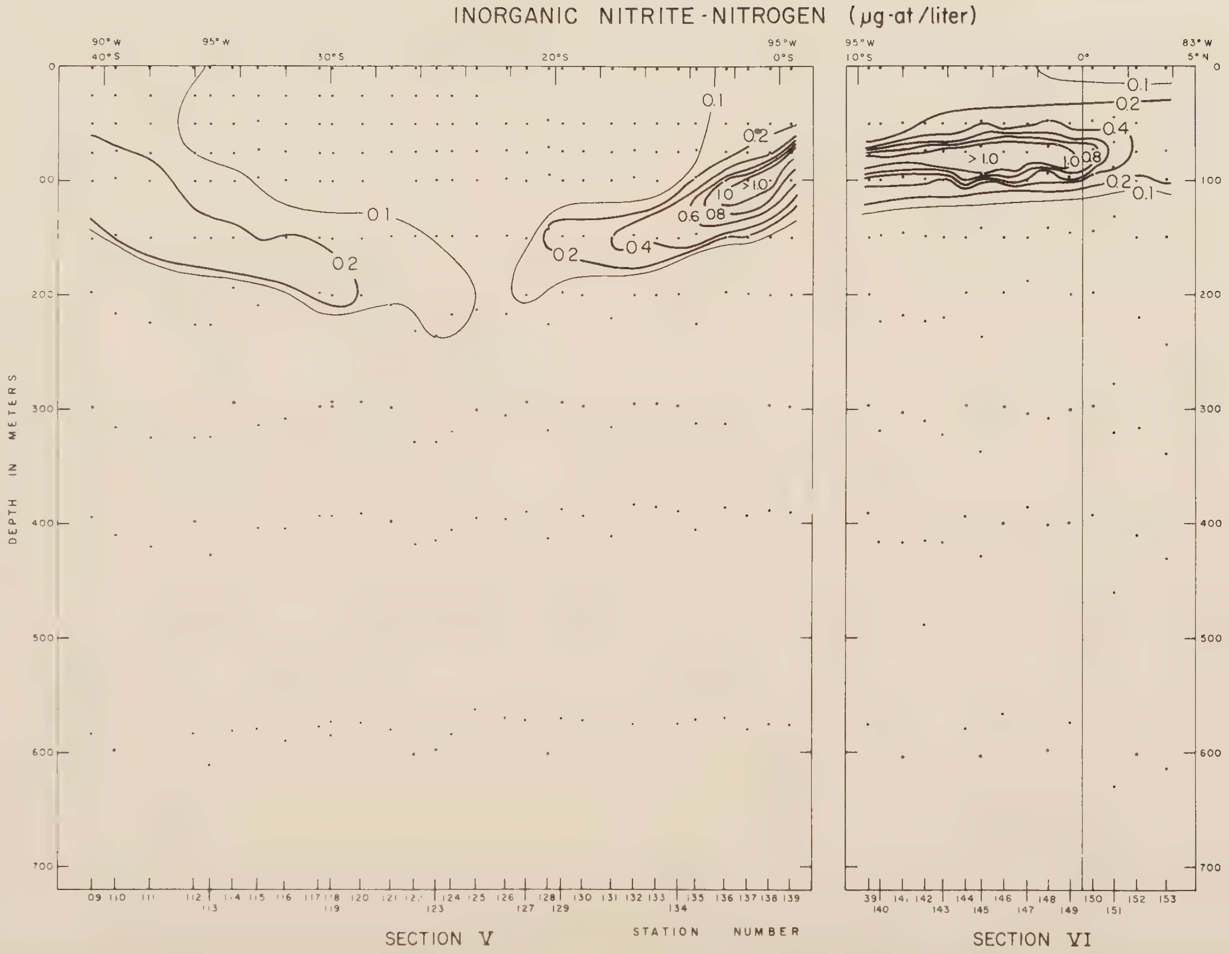


FIGURE 4f — FIGURA 4f

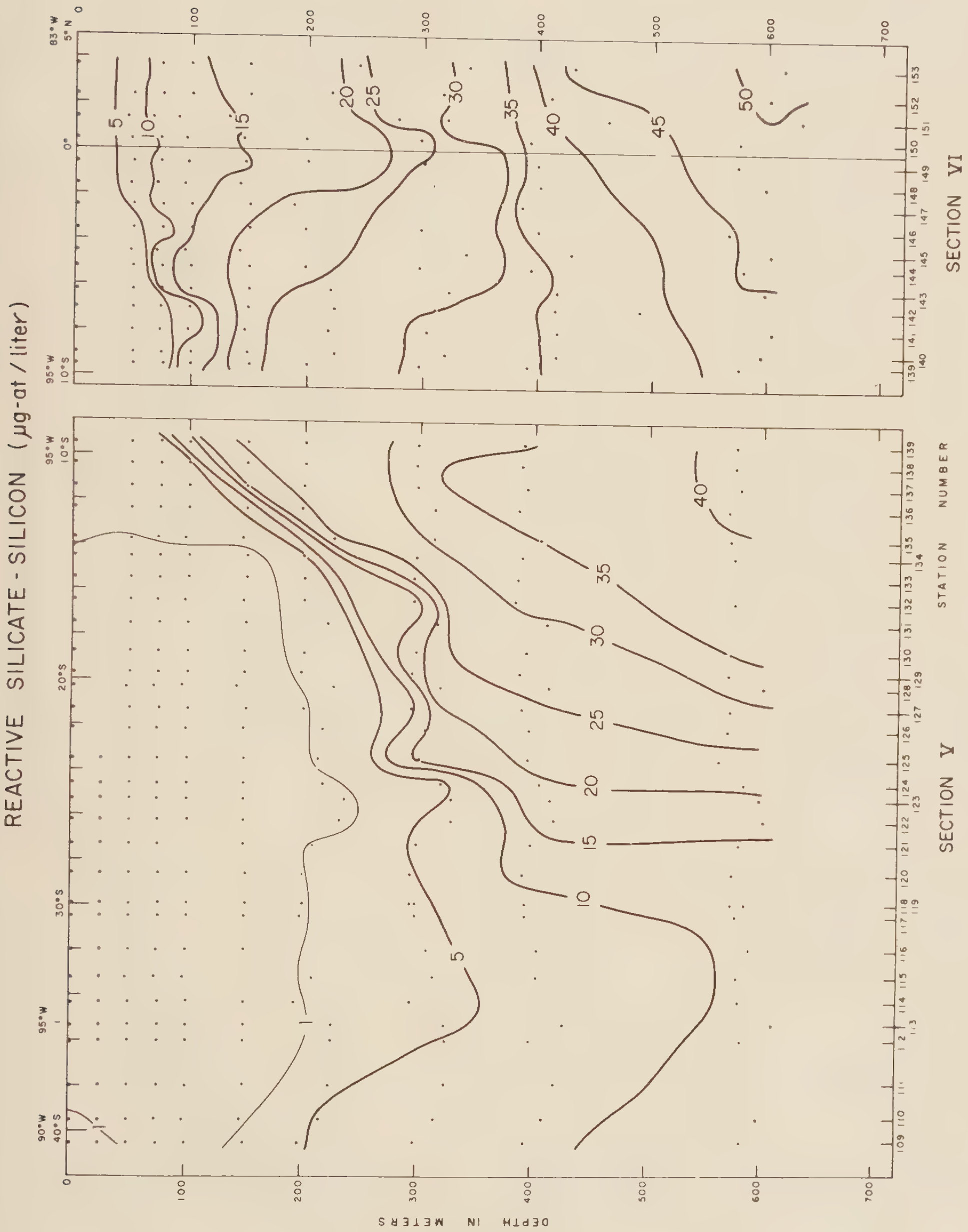


FIGURE 4g — FIGURA 4g

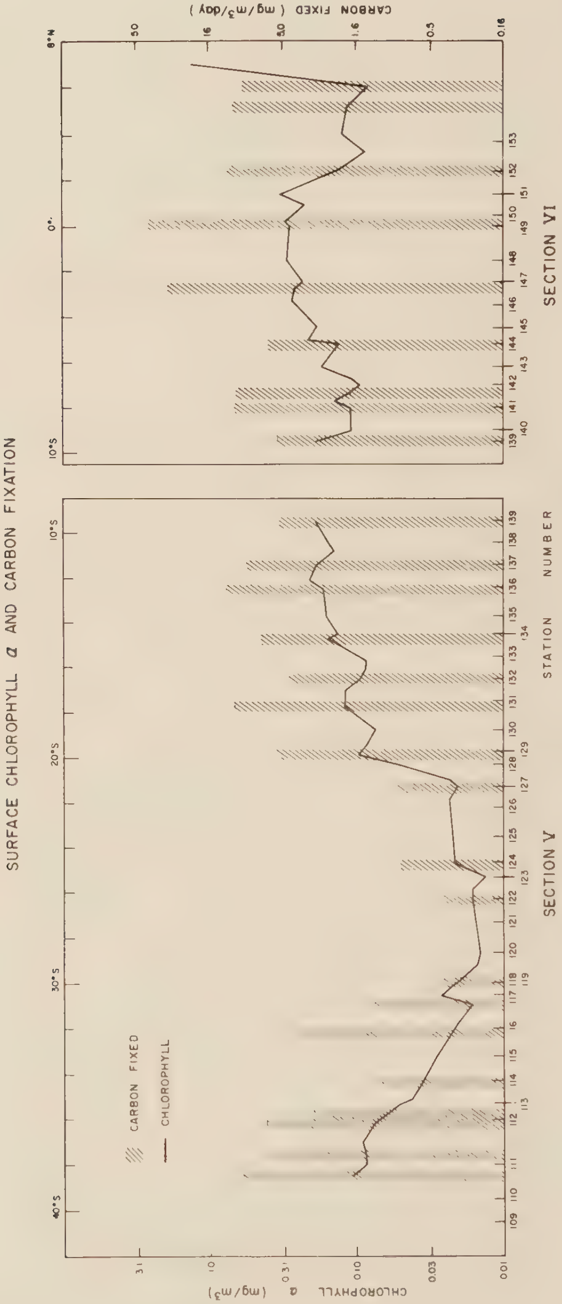


FIGURE 4h — FIGURA 4h

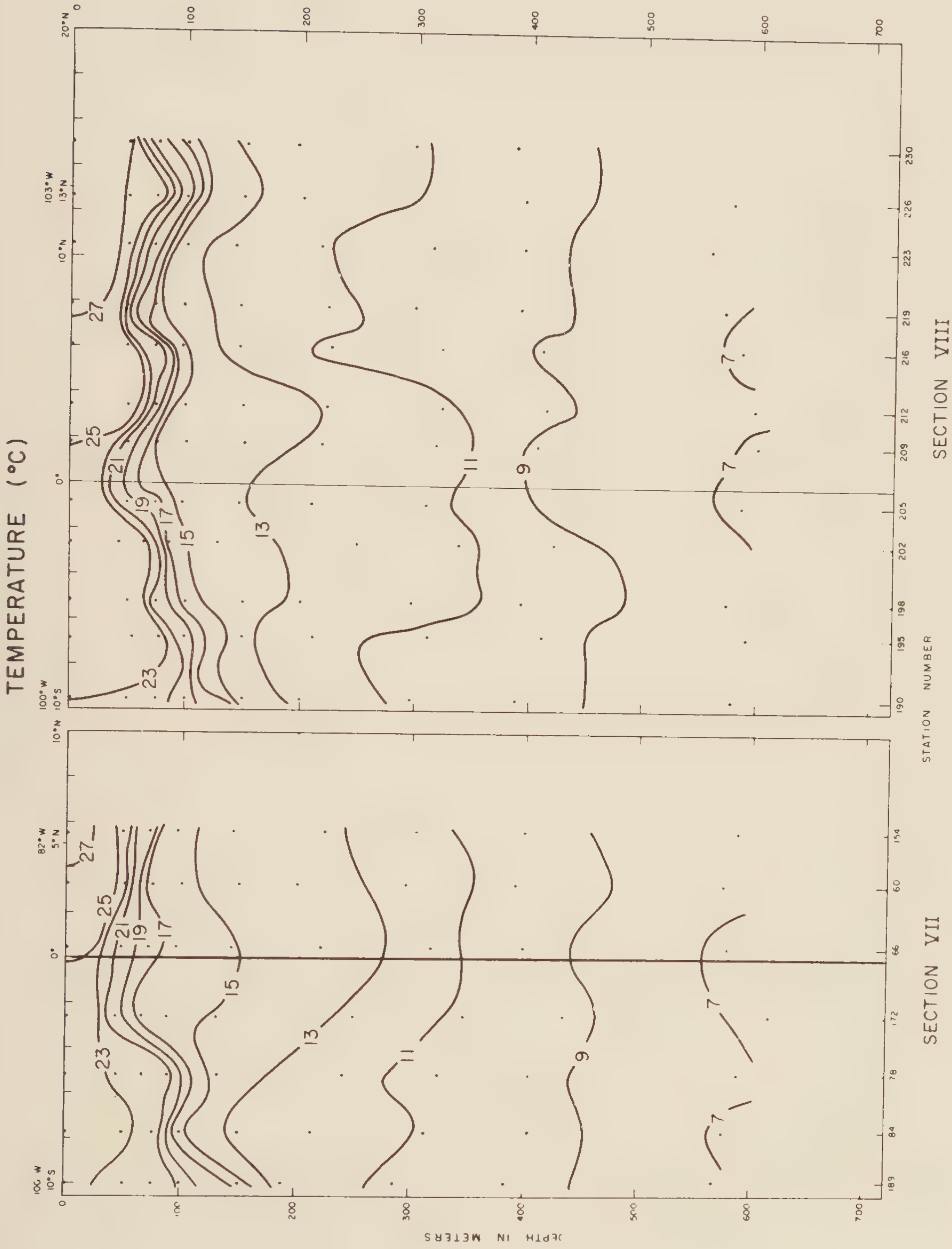


FIGURE 5a — FIGURA 5a

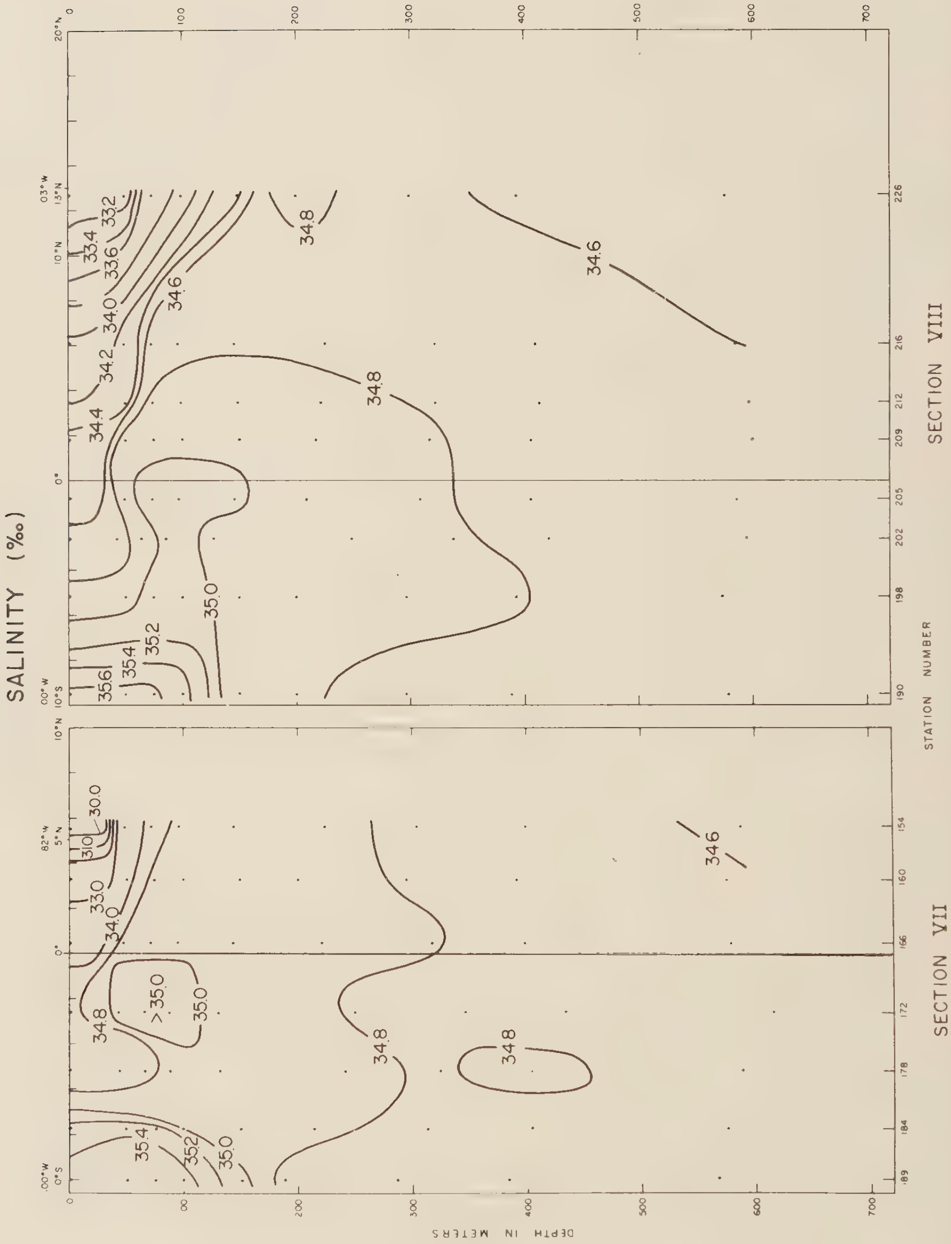


FIGURE 5b — FIGURA 5b

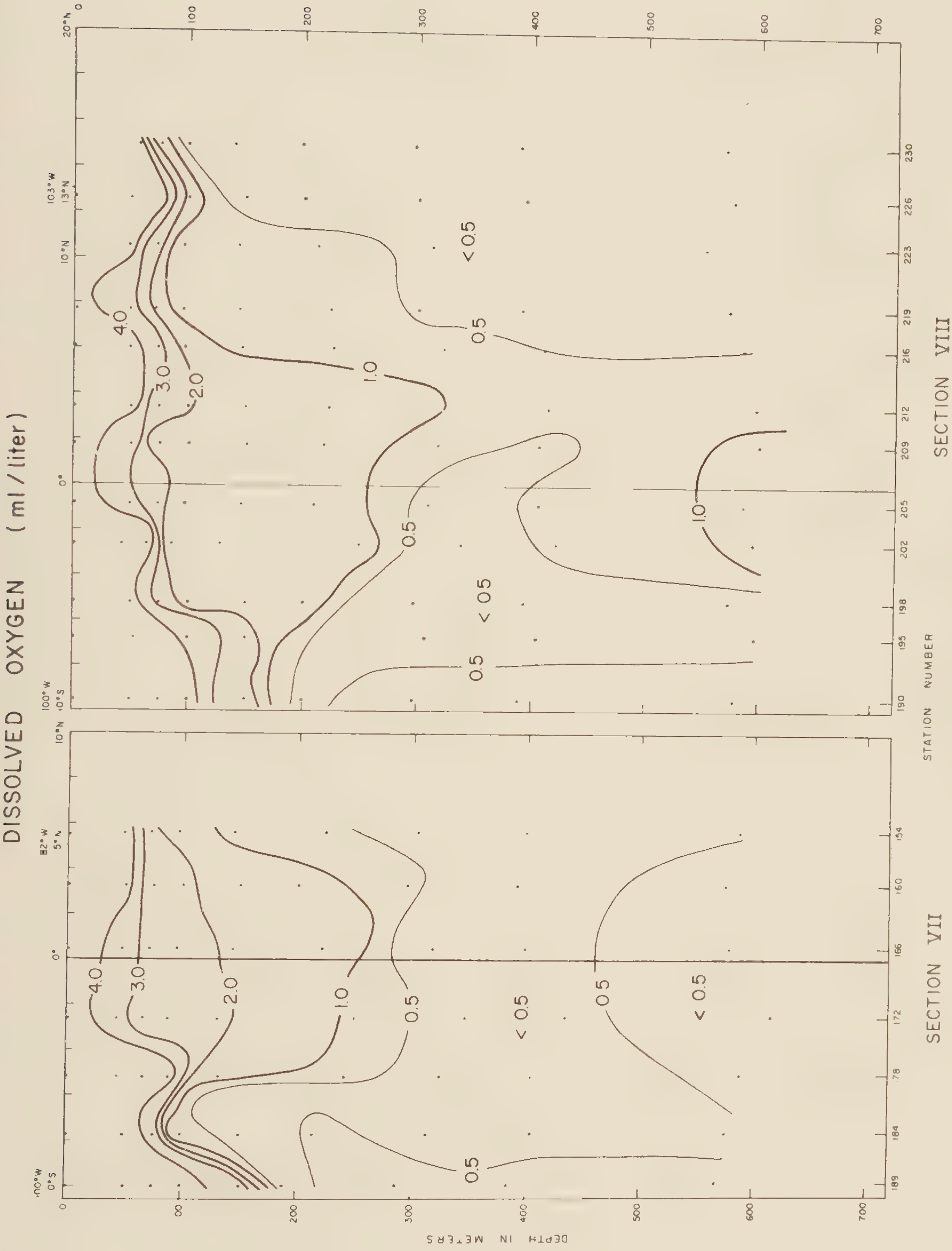
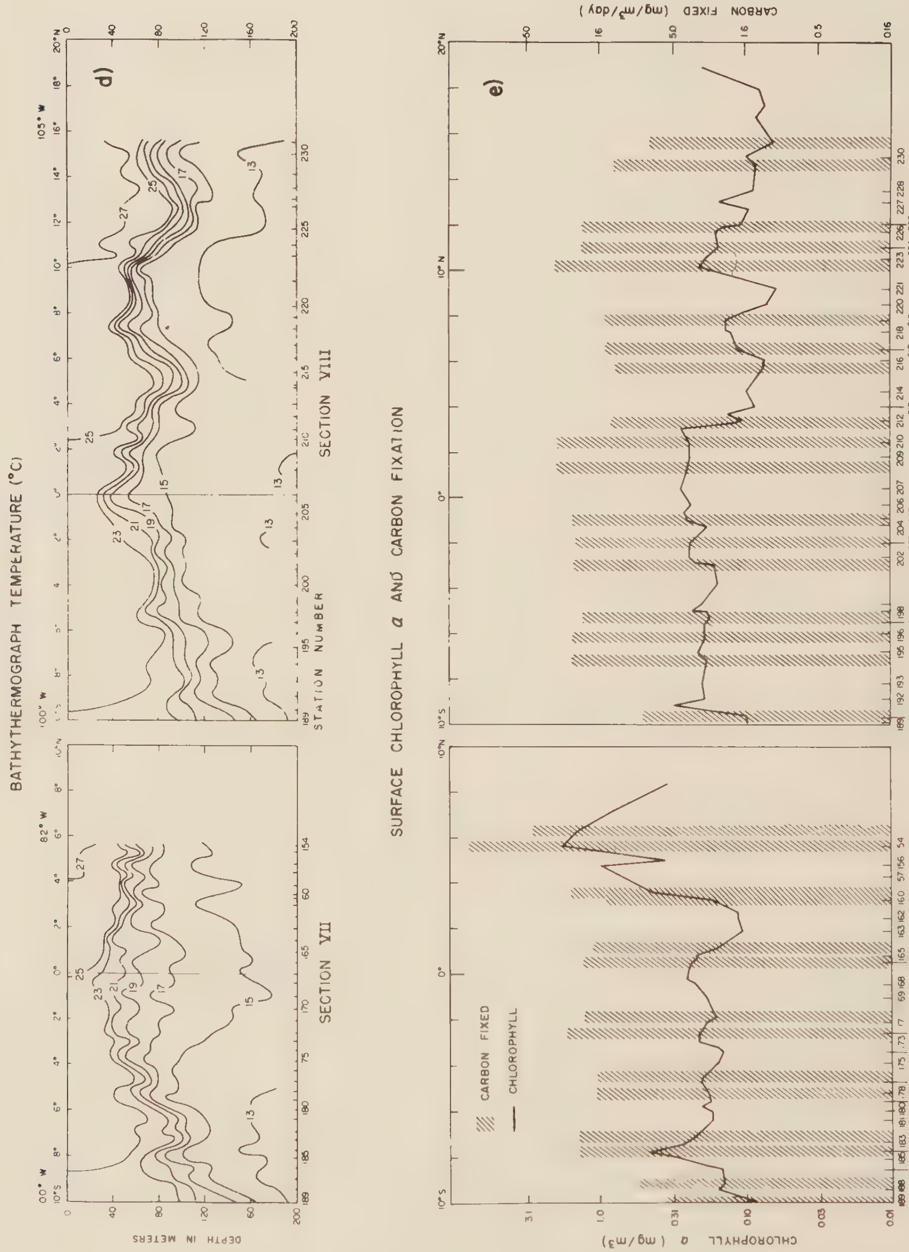


FIGURE 5c — FIGURA 5c



FIGURES 5d, e — FIGURAS 5d, e

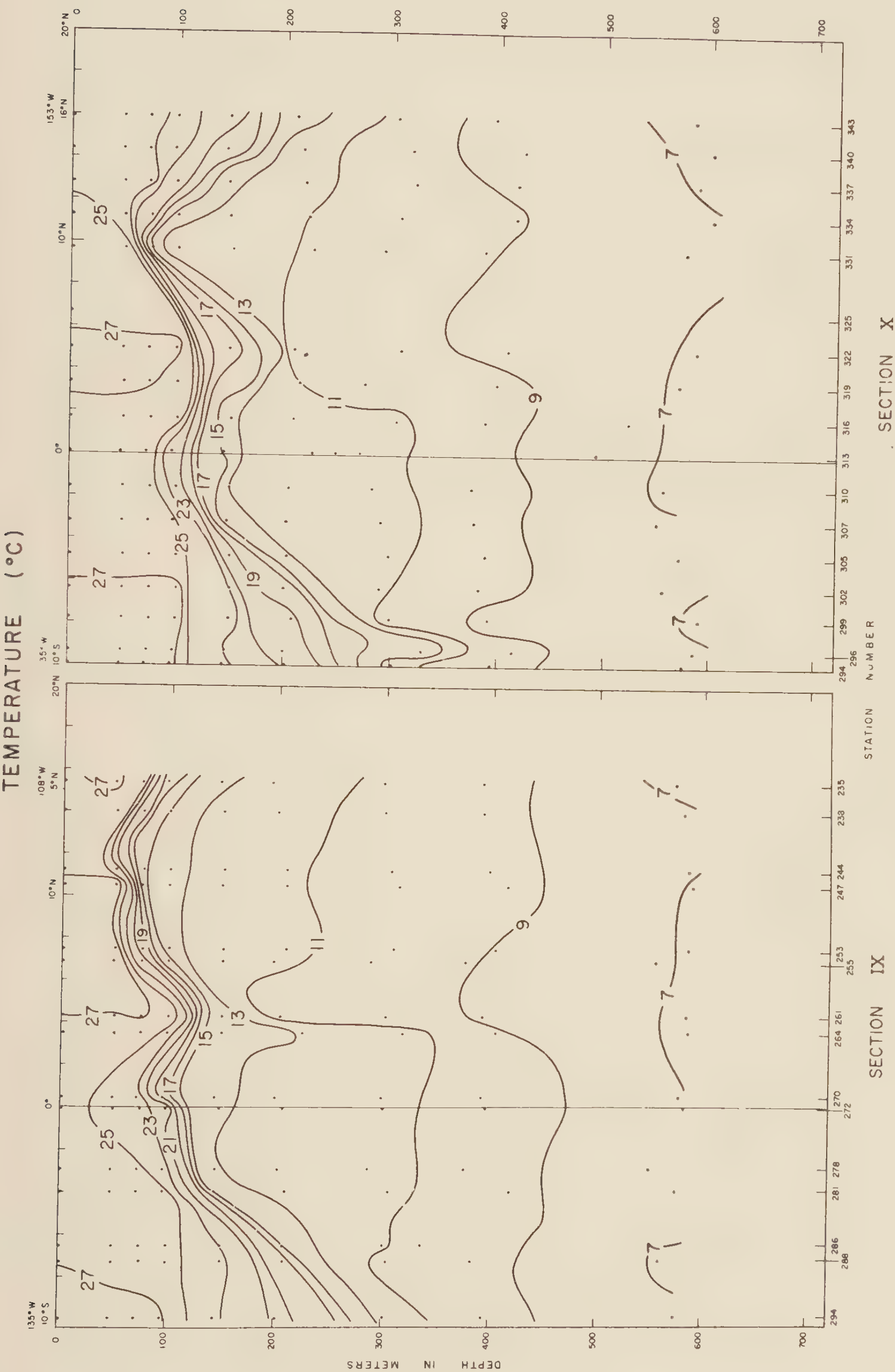


FIGURE 6a — FIGURA 6a

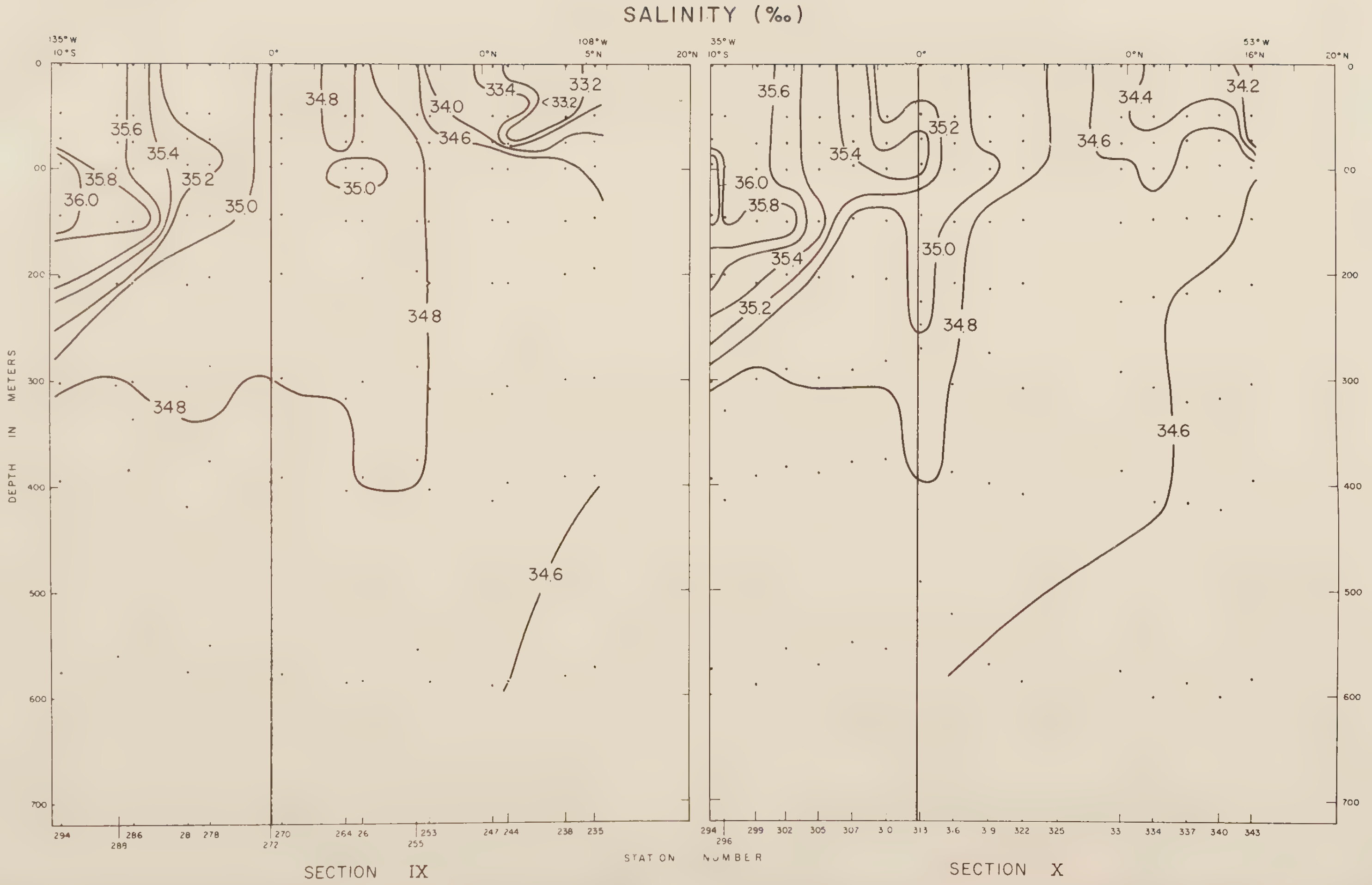


FIGURE 6b — FIGURA 6b

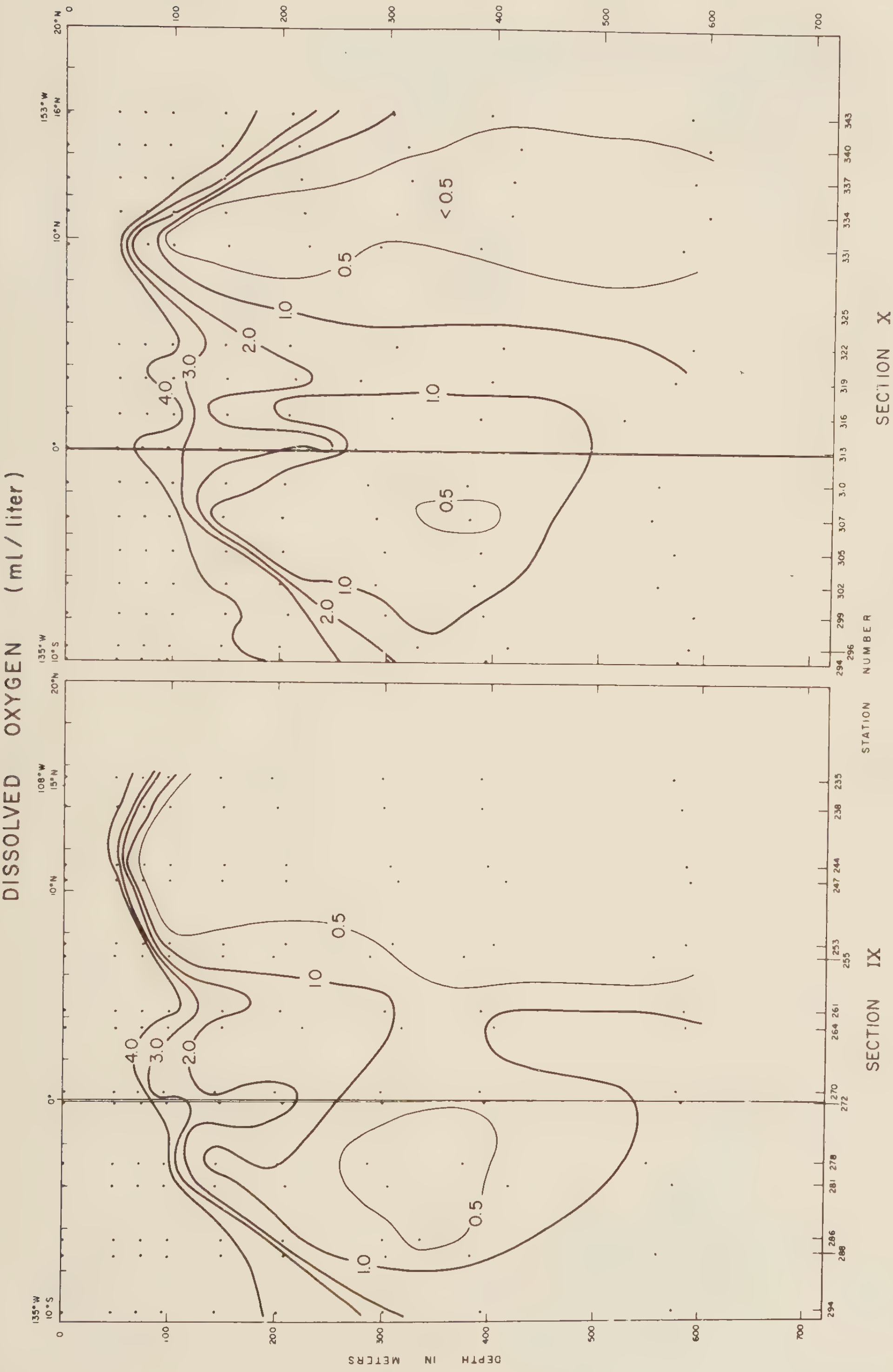
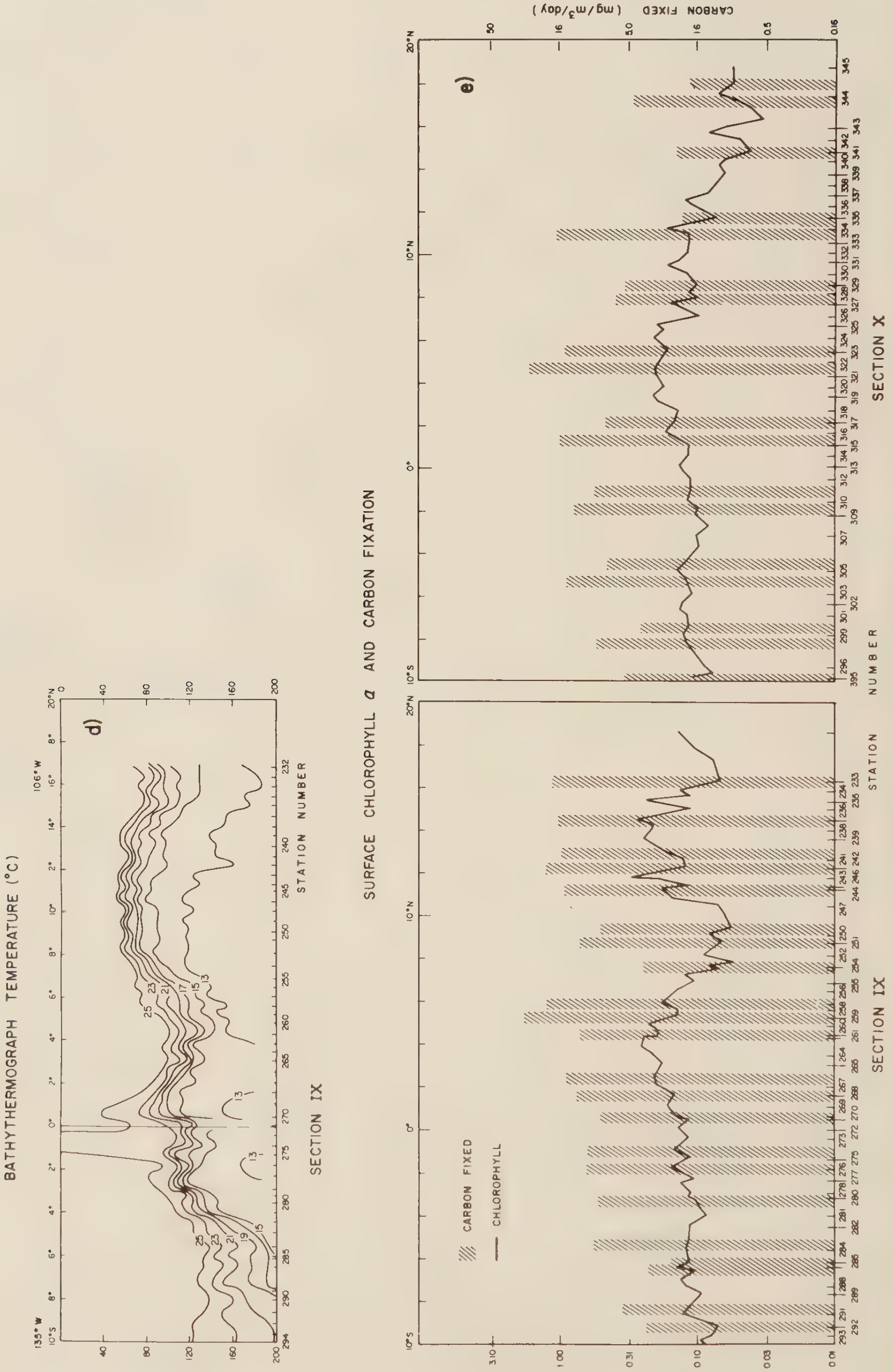


FIGURE 6c — FIGURA 6c



FIGURES 6d, e — FIGURAS 6d, e

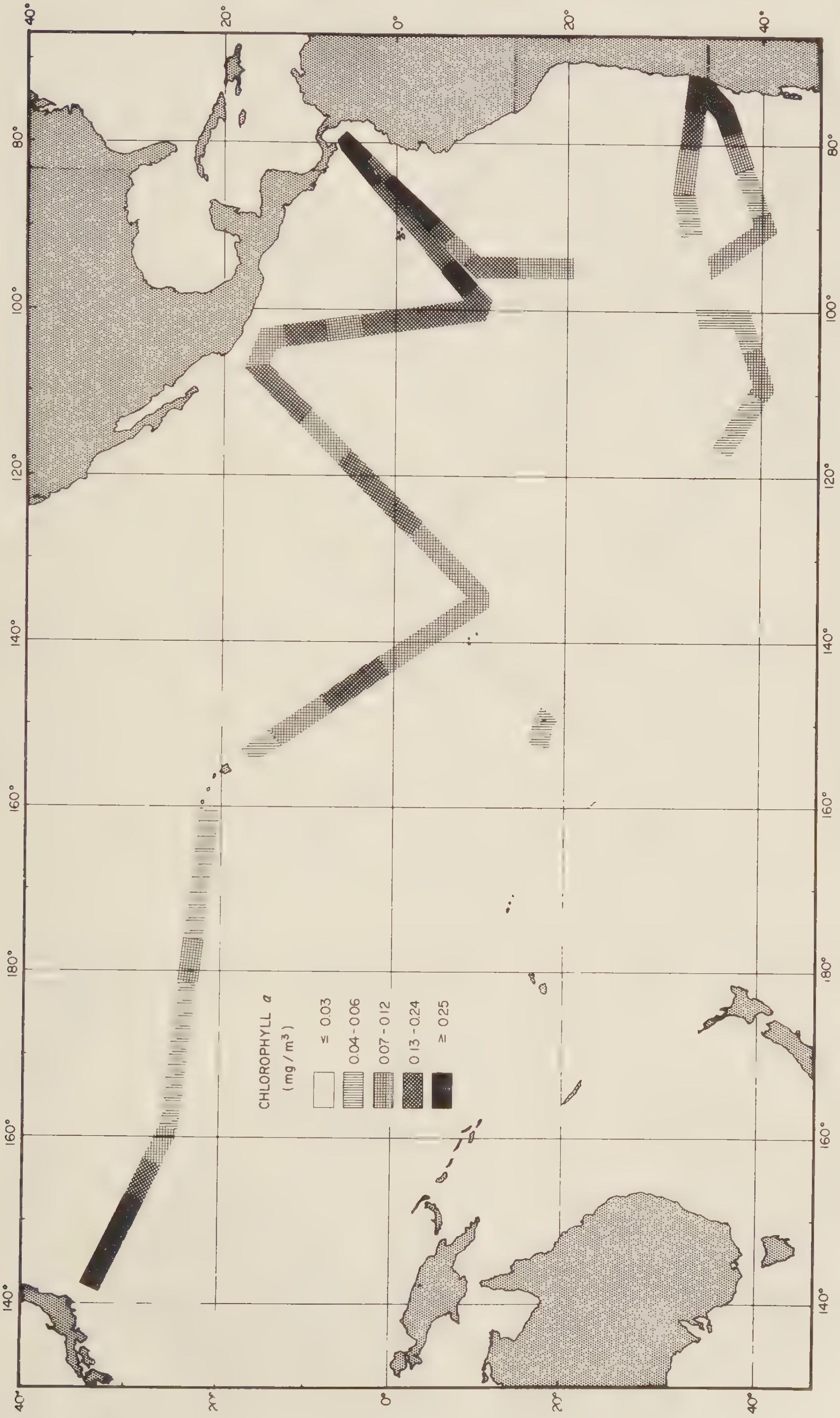

CHLOROPHYLL a
(mg/m³)
≤ 0.03
0.04-0.06
0.07-0.12
0.13-0.24
≥ 0.25
40°
20°
0°
20°
40°
80°
100°
120°
140°
160°
180°
160°
140°

FIGURE 7a — FIGURA 7a

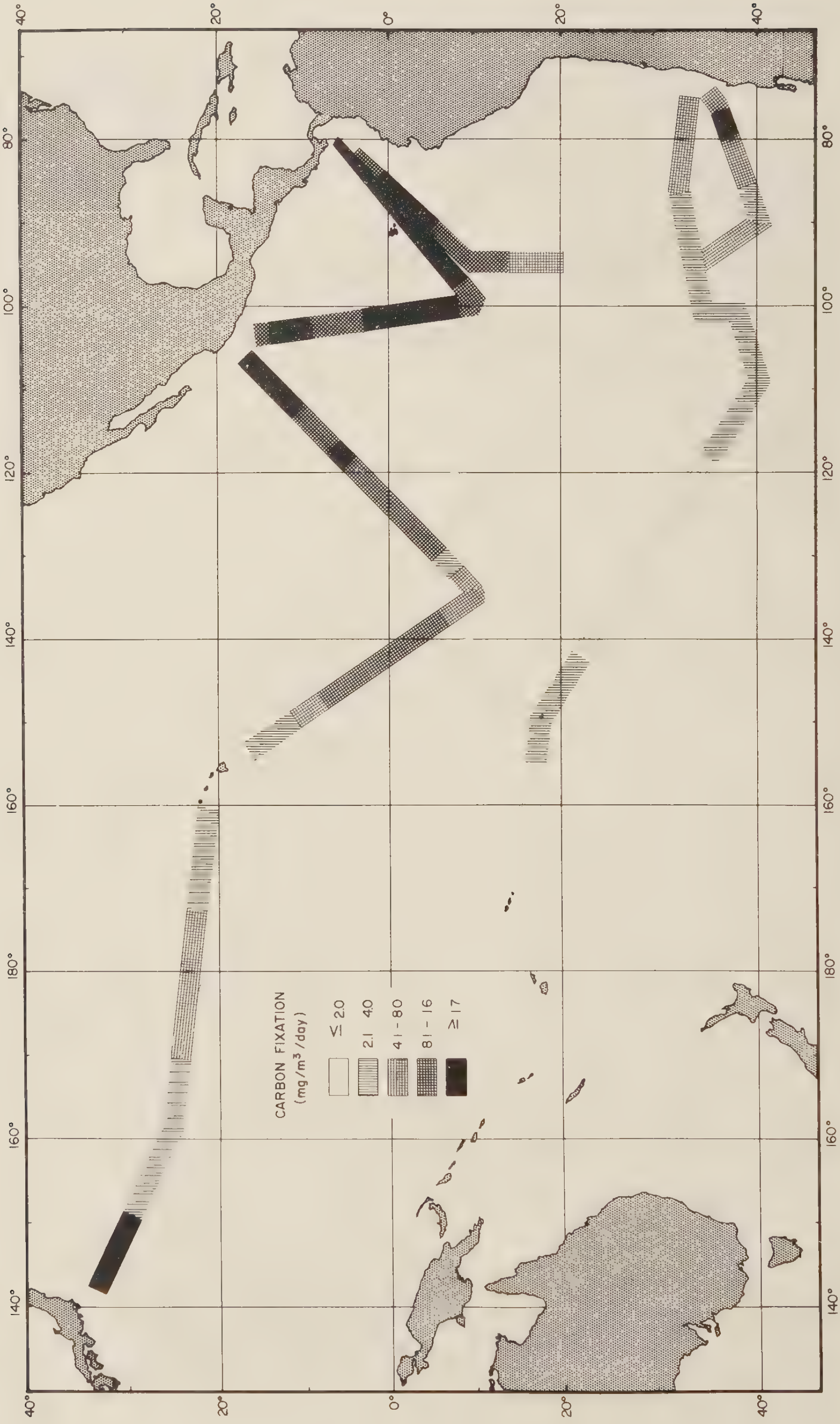

40°
20°
0°
20°
40°
80°
100°
120°
140°
160°
180°
160°
140°
CARBON FIXATION
(mg/m³/day)
≤ 2.0
2.1 - 4.0
4.1 - 8.0
8.1 - 16
≥ 17

FIGURE 7b — FIGURA 7b

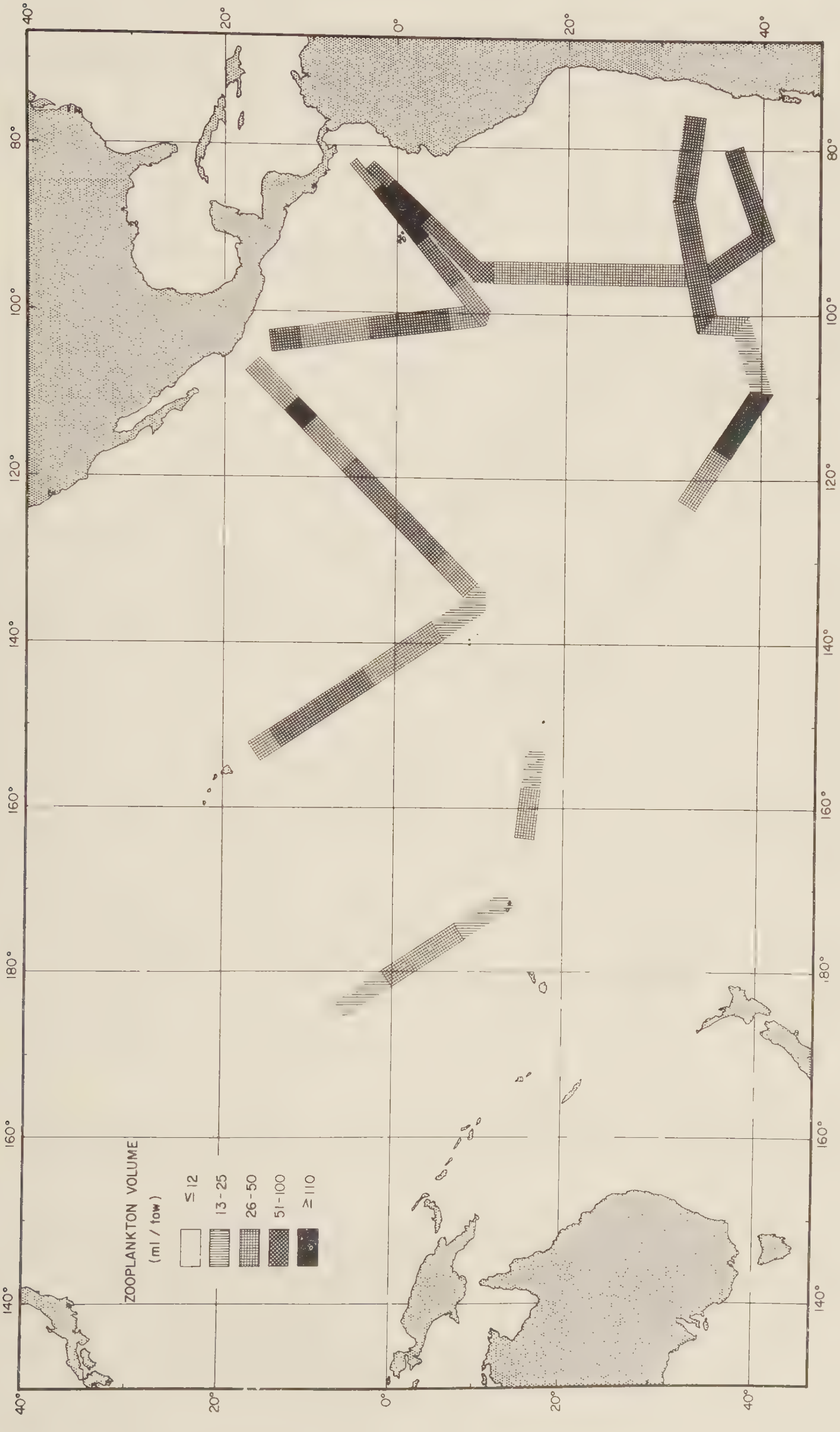

ZOOPLANKTON VOLUME
(ml / tow)
≤ 12
13-25
26-50
51-100
≥ 110
40°
20°
0°
20°
40°
80°
100°
120°
140°
160°
180°
160°
140°

FIGURE 7c — FIGURA 7c

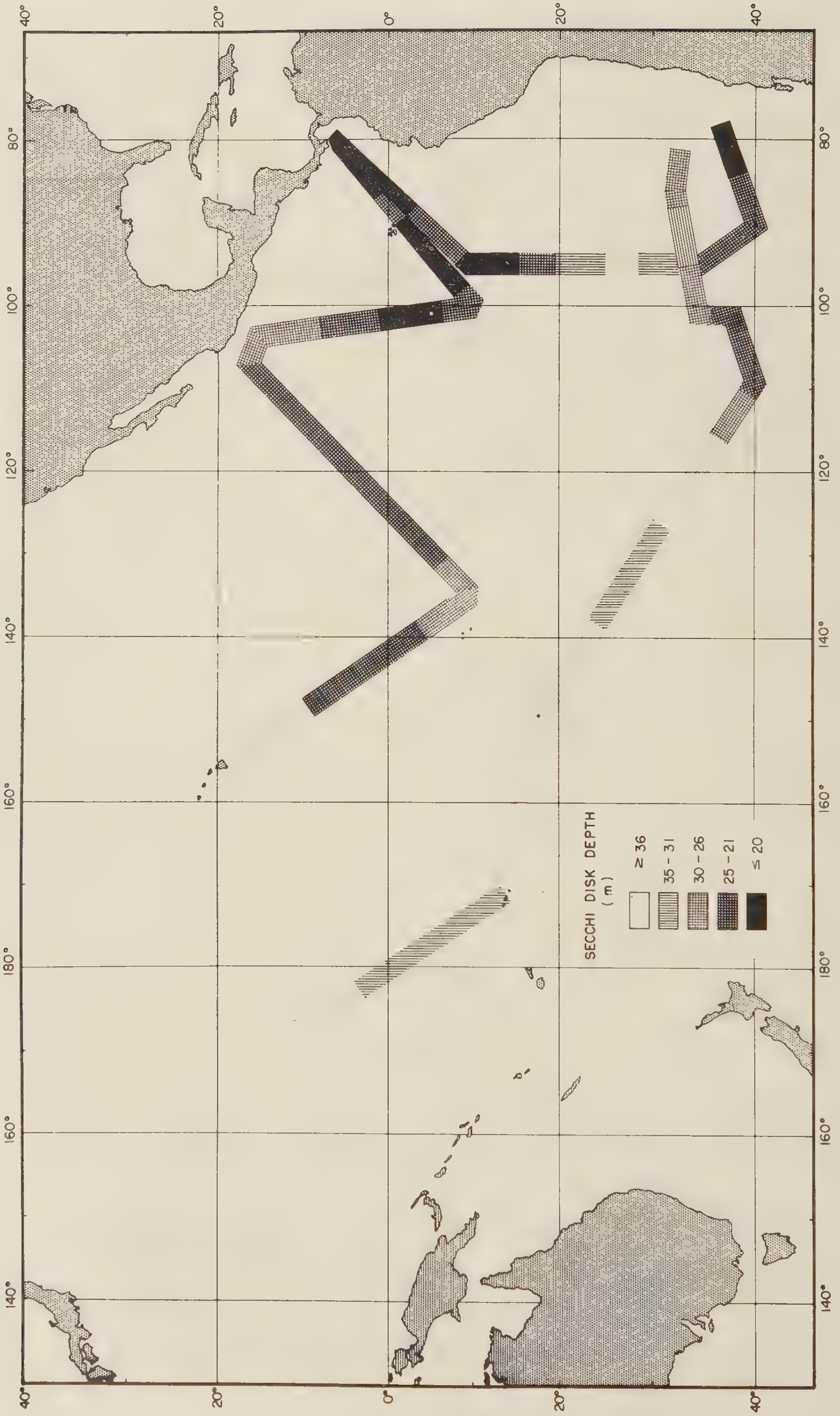

SECCHI DISK DEPTH
( m )
≥ 36
35 - 31
30 - 26
25 - 21
≤ 20
40°
20°
0°
20°
40°
80°
100°
120°
140°
160°
180°
160°
140°

FIGURE 7d — FIGURA 7d

# OBSERVACIONES OCEANOGRAFICAS DEL OCEANO PACIFICO ORIENTAL, RECOLECTADAS POR EL BARCO *SHOYO MARU* OCTUBRE 1963 - MARZO 1964

por

Eric D. Forsbergh y William W. Broenkow[1]

## INTRODUCCION

El Nankai Regional Fisheries Research Laboratory de Kochi, Japón, llevó a cabo una exploración pesquera con palangre y un reconocimiento hidrográfico en el Océano Pacífico oriental, a bordo del barco de investigacion *Shoyo Maru,* desde octubre de 1963 hasta marzo de 1964. Una invitación dirigida a la Comisión Interamericana del Atún Tropical para participar en el crucero, confirió a sus investigadores la oportunidad de hacer observaciones biológicas superficiales y conservar muestras de agua para el subsiguiente análisis de los nutrientes. El resultado de este reconocimiento es un conjunto de datos físicos, químicos y biológicos que abarcan una gran parte del sector medio oriental del Océano Pacífico.

El Nankai Laboratory, ha permitido generosamente que la Comisión del Atún publique todos los resultados oceanográficos. Incorporando los resultados de las dos agencias en un solo informe, los datos serán fácilmente accesibles para estudios detallados. Se suministra una lista completa de los datos en los Apéndices. Los valores observados de la temperatura, clorinidad, oxígeno, estado atmosférico, estado del mar, transparencia del agua y de los volúmenes de zooplancton han sido también presentados por el Japan Ministry of Agriculture and Forestry, Fishing Agency, Investigation Research Division, First Research Section (1964).

No se ha tratado de interpretar extensamente estos datos, pero se han descrito brevemente algunas características de interés general. Se espera que este informe sea el complemento de estudios previos descriptivos del Océano Pacífico oriental tropical, tales como los de Wooster y Cromwell (1958) y Bennett (1963).

## PERSONAL CIENTIFICO

El siguiente personal científico participó en el Crucero No. 13 del *Shoyo Maru:*

| | |
|---|---|
| Dr. Yoichi Yabuta | Japan Fisheries Agency |
| Jefe de Investigación | Nankai Regional Fisheries Research Laboratory |
| Sr. Kozo Nagai | Japan Fisheries Agency, Second Deep Sea Section |

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[1] U.S. Bureau of Commercial Fisheries, Tuna Resources Laboratory, La Jolla, California. *Dirección actual:* Department of Oceanography, University of Washington, Seattle, Wash. 98105.

| | |
|---|---|
| Sr. Keiichiro Mori | Japan Fisheries Agency, Nankai Regional Fisheries Laboratory |
| Sr. Izumi Nakamura | Kyoto University, Department of Fisheries |
| Sr. Susumu Kato | U.S. Bureau of Commercial Fisheries, Tuna Resources Laboratory |
| Sr. Witold L. Klawe | Comisión Interamericana del Atún Tropical |
| Sr. Eric D. Forsbergh | Comisión Interamericana del Atún Tropical |

## RECONOCIMIENTO

Los autores están agradecidos con el Japan Fisheries Agency y el Nankai Regional Fisheries Research Laboratory, por invitar a la Comisión Interamericana del Atún Tropical para participar en el Crucero No. 13 del *Shoyo Maru*. Estamos especialmente obligados con el Dr. Yoichi Yabuta y sus colegas por su inapreciable asistencia y con el Capitán Sadamu Tanabe, sus oficiales y la tripulación del *Shoyo Maru* por su cooperación entusiástica. También estamos muy agradecidos con el Sr. Joseph L. Reid, el Dr. Milner B. Schaefer, el Dr. Warren S. Wooster, el Sr. Hajime Yamanaka y el Dr. Ichiro Yamanaka por la revisión crítica de este manuscrito. Deseamos agradecer también al Sr. Witold L. Klawe por recolectar muchos de los datos biológicos y al Sr. Susumu Kato quien le asistió; al Sr. Edward B. Bennett por su consejo y criticismo; y al Sr. Christopher T. Psarópulos por escribir los programas del computador.

El U.S. Bureau of Commercial Fisheries, Tuna Resources Laboratory en La Jolla, California, suministró ayuda en los análisis de las muestras.

## METODOS

Además de las operaciones pesqueras con palangre, los investigadores del Nankai Laboratory hicieron lanzamientos hidrográficos, titulaciones de clorinidad, análisis de oxígeno, arrastres con redes para la recolección de larvas, observaciones meteorológicas y batitermográficas, y descendimientos del disco Secchi. El personal de la Comisión del Atún preservó muestras de agua para los análisis de los nutrientes y de los pigmentos de las plantas, y condujo experimentos de la fijación de carbono a bordo. Los análisis de los nutrientes y de los pigmentos fueron hechos en tierra firme por científicos del Bureau of Commercial Fisheries y de la Comisión del Atún.

### Distancia entre las estaciones

Como el propósito principal del reconocimiento fue investigar la pesquería, las estaciones hidrográficas fueron más espaciadas de lo que se hubiera planeado para solamente un reconocimiento oceanográfico. Se proyectó que las estaciones hidrográficas estuvieran separadas de 120 a 160 millas, con dos estaciones de superficie y lanzamientos batitermográficos entre ellas. El batitermógrafo cesó de funcionar en la estación H-89 (Fig. 1), y para compensar esta pérdida de datos, las estaciones hidrográficas desde la H-89 hasta la H-153 fueron hechas aproximadamente con 60 millas de intervalo. Después de la estación H-153 se volvió a asumir el espacio original de las estaciones hidrográficas, ya que con el reemplazo del batitermógrafo fue posible reanudar estas observaciones.

### Profundidad

Dos lanzamientos de botellas Nansen fueron hechos en cada estación hidrográfica. Para el primer lanzamiento se descendieron las botellas hasta una profundidad nominal de 25, 50, 75, 100 y 150 m, y se determinaron las profundidades actuales del muestreo por medio del ángulo del cable. En el segundo lanzamiento a profundidades nominales de 200, 300, 400 y 600 m se utilizaron termómetros reversibles sin protección, siendo la profundidad actual del muestreo determinada termométricamente.

### Temperatura

Las temperaturas de la subsuperficie fueron determinadas usando un solo termómetro reversible protegido en cada botella Nansen. Los descendimientos batitermográficos fueron hechos hasta cerca de 200 m en cada estación hidrográfica y frecuentemente entre estaciones. Las temperaturas de la superficie fueron determinadas por un termómetro de cubo. La precisión de la lectura de un solo termómetro reversible es de cerca de ±0.04 C (Wooster y Taft, 1958).

### Clorinidad

Las determinaciones de la clorinidad fueron hechas a bordo por medio de la titulación estándar de nitrato de plata, usando el fluorescein como indicador. La precisión de los análisis fue alrededor de $\pm 0.03^0/_{00}$ Cl, o cerca de $\pm 0.06^0/_{00}$ S (Strickland y Parsons, 1960).

### Oxígeno disuelto

Los análisis del oxígeno disuelto fueron ejecutados a bordo, se usó la titulación de Winkler de tiosulfato de sodio. La precisión del método es por ahí de ±0.03 ml/L (Strickland y Parsons, 1960).

### Nutrientes

Inmediatamente después de que se terminaron las estaciones hidrográficas, se sacaron de las botellas Nansen que estaban dentro de bolsas de polietileno, muestras de 250 ml de agua de mar, las que fueron colocadas dentro de otras bolsas protectivas y se congelaron. Las muestras fueron guardadas a una temperatura de −10 hasta −15 C para su envío a San Diego, California, para su análisis correspondiente. El tiempo máximo de almacenaje fue de 24 semanas. El efecto de la congelación sobre la exactitud del análisis no fue determinado, pero Stefansson y Richards (1963) han demostrado que hay un buen acuerdo entre las muestras analizadas frescas y las analizadas después de haber sido congeladas (sus muestras para analizar el fosfato estuvieron en depósito 4 semanas, para el nitrato 2 semanas y aquellas para el silicato 10 semanas).

Se dejaron las muestras en el laboratorio para que se descongelaran durante la noche a la temperatura del cuarto. Se filtraron a través de un papel filtrador Whatman #42, y se analizaron según el método descrito por Strickland y Parsons (1960): para el nitrógeno inorgánico en forma de nitrito, se usó sulfanilamida y N-(1-naftil)-etileno-diamina para el desarrollo del color; para el nitrógeno inorgánico en forma de nitrato, por medio de la reducción con hidrazina y el análisis subsecuente de nitrato; y para el silicio reactivo en forma de silicato se usó metol-sulfato y ácido oxálico para reducir el complejo silico-molibdato. El análisis del fósforo inorgánico en forma de fosfato fue hecho por medio de la utilización de ácido ascórbico, método de J. P. Riley de tartrato antimónico de potasio segun ha sido descrito por J. D. H. Strickland y T. R. Parsons (*sin publicar*). La precisión de los análisis fue: fosfato, ±0.03 $\mu$g-at/L; nitrato, ±0.3 $\mu$g-at/L al nivel de 4.5 $\mu$g-at/L y ±1.3 $\mu$g-at/L al nivel de 30 $\mu$g-at/L; nitrito, ±0.03 $\mu$g-at/L; y silicato ±0.25 $\mu$g-at/L al nivel de 10 $\mu$g-at/L y ±1.4 $\mu$g-at/L al nivel de 60 $\mu$g-at/L (según Strickland y Parsons, 1960, y *sin publicar*).

### Pigmento de las plantas

Las muestras de agua de la superficie fueron recolectadas con un cubo, se agregó carbonato de magnesio y las muestras fueron inmediatamente filtradas por medio de filtros de cristal Whatman GF/C. Durante la filtrada se mantuvo la succión a presiones entre 25 y 35 cm de mercurio. Se desecaron los filtros al vacío en la obscuridad. Las muestras se mantuvieron secas y congeladas en la obscuridad hasta 6 semanas antes del análisis, período de tiempo máximo permitido, considerado para tal depósito por Parsons y Strickland (1960). Los análisis del pigmento de las plantas fueron hechos por el método de Richards con Thompson (1952), en el laboratorio de San Diego. Se computaron las concentraciones haciendo uso de las ecuaciones de Parsons y Strickland (1963). Las precisiones de los análisis fueron según J. D. H. Strickland y T. R. Parsons (*sin publicar*): clorofila *a*, ±0.05 mg/m$^3$ al nivel de 1 mg/m$^3$; clorofila *b*, ±0.04 mg/m$^3$ al nivel de 0.1 mg/m$^3$; carotenoides de las plantas, ±0.03 mSPU al nivel de 0.3 mSPU. Las determinaciones de la clorofila *c* son inexactas y sin precisión.

En 28 ocasiones las muestras fueron simultáneamente filtradas a través de filtros Whatman GF/C con filtros Millipore HA por debajo. Esto se hizo para determinar la cantidad de fitoplancton que fue retenida por los filtros de cristal, comparándola con la retenida por los filtros Millipore. En promedio el 80% (con una amplitud de 64% hasta 96%) de fitoplancton fue retenido por el filtro de cristal como lo indicaron las medidas de 665 m$\mu$ de la densidad óptica. Para compensar la pérdida a través de los filtros de cristal, todos los valores de los pigmentos fueron multiplicados por lo tanto, por el factor de 1.25.

Se extrajeron los pigmentos durante 18 horas de la estación H-26 hasta la estación H-153; de la estación H-154 a la estación P-98 los filtros de cristal y el fitoplancton fueron pulverizados en un tejido pulverizador por el método de Yentsch y Menzel (1963), y se extrajeron los pigmentos por dos horas. La relación entre la fijación de carbono y la clorofila *a* según ha sido determinada por los dos métodos de extracción fue esencialmente la misma. Así que parece que en este caso los dos métodos de la extracción de los pigmentos dieron resultados similares.

### Fijación de carbono

La tasa de la fijación de carbono del fitoplancton de la superficie, fue medida por medio del empleo del método de radiocarbono (carbono $^{14}$) de Steemann Nielsen (1952). Muestras del agua de la superficie fueron recolectadas con un cubo de polietileno. Se incubaron a la temperatura de la superficie del mar bajo la luz natural entre el orto y el mediodía o entre el medio día y el ocaso. Los procedimientos para la estandarización, la enumeración y los cálculos son idénticos a los presentados por Forsbergh y Joseph (1964). La misma solución de radiocarbono fue usada en todo el crucero. Se agregaron veinte mC de radioactividad a cada muestra. La precisión al nivel de 15 mg C/m$^3$ día fue ±1.5 mg C/m$^3$ día (según Strickland y Parsons, 1960).

### Zooplancton

La descripción de las redes para la recolección de larvas y su procedimiento ha sido presentado por el Japan Ministry of Agriculture and Forestry, Fishery Agency (1964). La red de superficie era de 1.4 m en diámetro y fue arrastrada a una velocidad de 2 nudos, durante 10 minutos. La red de profundidad media era de 2.0 m en diámetro y fue arrastrada a la misma velocidad a unos 20 m de profundidad, durante 10 minutos. Los volúmenes de zooplancton húmedo que fueron recolectados por medio de estas redes fueron medidos por desplazamiento. Los volúmenes de los organismos de una longitud mayor de 5 cm fueron medidos separadamente.

Griffiths (1963), habiendo usado la variancia total, ha demostrado que el 95% de los límites de confianza de un solo arrastre oblicuo de zooplancton es 1/3 y 3 veces el valor del arrastre, que probablemente se aproxima a los límites de confianza de los arrastres horizontales.

## TRATAMIENTO DE LOS DATOS

Todos los cómputos de los datos y las interpolaciones fueron procesados por el computador 3600 del Control Data Corporation (véase Apéndice D referente a los métodos del programa). A profundidades observadas, fue determinada la densidad según las observaciones de temperatura y clorinidad. Tanto los valores de la temperatura como de la densidad, fueron interpolados a profundidades estándar por medio de interpolaciones logarítmicas de dos puntos. Los valores de la salinidad a profundidades estándar, fueron computados por medio de estos valores interpolados de temperatura y densidad.

Unicamente las variables oceanográficas observadas han sido ilustradas en este informe. Las propiedades computadas tales como las de los valores interpolados, la densidad, la función del transporte y la utilización aparente del oxígeno no han sido usadas.

Se dibujaron las secciones para que la distribución de todas las variables fueran consistentes una con otra. Puntos anómalos de los datos fueron eliminados, basándose en la inconsistencia entre la distribución de las diferentes propiedades. Estos resultados aparentemente erróneos han sido anotados en el registro de los datos. Las isopletas fueron diseñadas por interpolación linear, excepto en el caso de la temperatura en donde se dispuso de los datos batitermográficos (Secciones I, VII, VIII y IX). En estos casos las secciones batitermográficas fueron primero dibujadas, luego el espacio isotérmico fue diseñado entre las estaciones hidrográficas de acuerdo a los datos batitermográficos.

Se dibujaron secciones con una escala linear tanto para la latitud como para la longitud. Las exageraciones verticales de las secciones varían porque están orientadas a diferentes ángulos hacia el meridiano. Las exageraciones verticales aproximadas son:

| | | | |
|---|---|---|---|
| Sección I | 6,700:1 | Sección VI | 7,600:1 |
| Sección II | 10,900:1 | Sección VII | 8,400:1 |
| Sección III | 9,300:1 | Sección VIII | 5,700:1 |
| Sección IV | 10,800:1 | Sección IX | 8,000:1 |
| Sección V | 5,800:1 | Sección X | 6,800:1 |

A causa de que las determinaciones para las muestras de pigmentos fueron tomadas a diferentes horas del día, se hizo un esfuerzo para averiguar el ciclo diurno en las concentraciones de pigmentos. Las concentraciones de clorofila *a* fueron agrupadas por tiempo de recolección. Pruebas medianas y de rango no mostraron diferencias significativas en las concentraciones de clorofila *a* entre los grupos de tiempo. Por lo tanto no se corrigieron los datos de tiempo de la recolección.

La distribución de la clorofila *a* superficial correspondiente a las secciones físicas y químicas, está indicada por líneas gráficas porque las observaciones estaban muy juntas para ser indicadas como barras gráficas. Los valores de la fijación de la clorofila *a* y del carbono están indicados en escalas logarítmicas para facilitar su lectura.

La distribución de las variables biológicas fue construida de las medias sucesivas de los valores en estaciones consecutivas, con el fin de eliminar alguna de la variación debida a las agrupaciones de plancton y a la precisión inferior de los métodos. El número de observaciones utilizado en cada una de las medias sucesivas fue elegido para que así las distancias comparativas fueran representadas por cada una de las medias. Debido a que las observaciones de la fijación de carbono estaban muy separadas, se usaron valores individuales. La distribución areal de la clorofila *a* (Fig. 7a) está representada por medias sucesivas de valores de 5 estaciones consecutivas.

Para construir la distribución areal del volumen de zooplancton (Fig. 7c), se computaron los factores para corregir las diferencias en el volumen del zooplancton debidas a la migración diurna, dependiente de la profundidad y del tamaño de la red del muestreo. El arrastre de la red puede ser dividido en cuatro tipos: a) arrastres de superficie nocturnos, b) arrastres de superficie diurnos, c) arrastres nocturnos a 20 m, y d) arrastres diurnos a 20 m. Los volúmenes recolectados por estos arrastres fueron comparados en estaciones individuales y entre estaciones adyacentes. Los valores medianos de las razones de cada comparación se usaron como factores para determinar los volúmenes equivalentes a los arrastres superficiales nocturnos:

| | |
|---|---|
| Arrastres superficiales diurnos | 4.0 |
| Arrastres nocturnos a 20 m | 0.2 |
| Arrastres diurnos a 20 m | 0.5 |

La distribución areal de zooplancton está indicada por las medias sucesivas de estos volúmenes corregidos de tres estaciones consecutivas.

La distribución areal de la transparencia del agua (Fig. 7d), está representada por medias sucesivas de las profundidades del disco Secchi de tres estaciones consecutivas.

## ELEMENTOS DE INTERES

Fuertes gradientes horizontales dominan la distribución de las propiedades de los sectores meridionales de las Secciones II y V (Figs. 3, 4). La precipitación de las isotermas que aquí son aproximadamente paralelas a las isopicnales, muestran los efectos de un flujo hacia el este de la corriente del viento oeste entre los extremos meridionales de estas secciones y cerca de los 25°S. En estas secciones al sur, la superficie del Agua Subantártica era fría y de baja salinidad (13 C, $34^{0}/_{00}$) comparada con la parte oriental de la masa de agua central del Pacífico Sur hacia el norte, cálida y de alta salinidad (27 C, $36^{0}/_{00}$). Se encontraron concentraciones apreciables de fosfato y nitrato, y escasamente concentraciones de silicato cerca a los 40°S. Se descubrieron concentraciones de nitrito únicamente en la termoclina, siendo la cantidad de nitrito mayor cerca a los 40°S. La naturaleza productiva del Agua Subantártica está demostrada por valores relativamente altos de clorofila *a*, y de la fijación de carbono en los sectores meridionales de estas secciones.

Se ve la evidencia de la Subcorriente Perú-Chile (Wooster y Gilmartin, 1961) en ambas Secciones III y IV (Fig. 3) entre los 200 y 300 m. La parte oriental de estas secciones muestran un centro de agua de salinidad relativamente alta, rico en nutrientes y pobre en oxígeno, que se atribuye al flujo meridional de la subcorriente.

El margen septentrional de la Corriente del Perú es claramente indicado en las Secciones VI y VII (Figs. 4b; 5b), por una gradiente aguda en la salinidad de la superficie a través del ecuador, en donde la alta salinidad del agua ($>35^{0}/_{00}$) de la Corriente del Perú se encuentra con el agua de baja salinidad ($<33^{0}/_{00}$) del Golfo de Panamá. La extensión hacia el oeste de la Corriente del Perú, afecta la distribución superficial de las propiedades como se demostró en la Sección V (Fig. 4). El agua de la superficie con concentraciones altas de nutrientes cerca a los 10°S, se origina probablemente en las áreas de afloramiento cerca a las costas del Perú y Chile, y fue transportada mar afuera por la Corriente del Perú. Estas aguas tienen valores altos de clorofila *a* y de fijación de carbono. La termoclina en la extensión hacia el oeste de la Corriente del Perú contiene concentraciones particularmente altas de nitrito.

El contenido de oxígeno disuelto disminuye hacia el norte en todas las profundidades como se indica en la Sección V (Fig. 4c). Se ha observado antes esta característica, y se asocia con una capa baja en oxígeno, orientada este-oeste en las aguas intermedias del Océano Pacífico oriental tropical (Wooster y Cromwell, 1958; Bennett, 1963). Hay dos de estas capas bajas en oxígeno en el Pacífico tropical; una al norte del ecuador y una al sur del ecuador. La del norte parece estar centralizada cerca a los 15°N en la Sección VIII (Fig. 5c) y por ahí a los 12°N en la Sección X. La capa meridional, baja en oxígeno está centralizada cerca a los 10°S en las Secciones V y VI (Fig. 4c), y a los 3°S en la Sección X (Fig. 6c). Ambas capas la del norte y la del sur, pobres en oxígeno, son notablemente más angostas al oeste que al este. Al este de las Islas Galápagos en las Secciones VI y VII, la capa baja en oxígeno es continua a través del ecuador.

La presencia de corrientes superficiales por zonas, es indicada por la estructura de la temperatura en las Secciones I, VIII, IX y X (Figs. 2a, d; 5a, d; 6a, d). La Corriente Ecuatorial del Norte y del Sur son la causa del declive ascendente de las isotermas hacia el ecuador. Estas corrientes parecen ser más fuertes en las secciones del oeste (Secciones I, X y IX). La Contracorriente Ecuatorial del Norte es la causa del declive ascendente de las isotermas hacia el norte. Esta contracorriente aparece entre los 3°N y los 8°N en la Sección I, entre los 4°N y los 10°N en ambas Secciones X y IX, y entre los 5°N y los 7°N en la Sección VIII.

Las isotermas cuya gradiente ascendente hacia el sur es indicada en la Sección I (Figs. 2a, d) entre los 8°S y los 10°S, Sección XI (Fig. 4a) entre los 8°S y los 10°S, Sección VII (Figs. 5a, d) entre los 7°S y los 9°S, Sección VIII (Fig. 5d) entre los 7°S y los 9°S, y en la Sección IX (Fig. 6d) entre los 6°S y los 8°S pueden ser tomadas como la evidencia de una débil Contracorriente Ecuatorial del Sur, habiendo sido descrita primero por Reid (1959). En las Secciones VIII y IX esta gradiente de las isotermas no está bien definida, y en la Sección X dicha gradiente no es aparente.

La evidencia de la Subcorriente Ecuatorial o Corriente de Cromwell (Knauss, 1960) es demostrada por las siguientes características en cada sección que atraviesa el ecuador: en la Sección I, por una termoclina débil

(Figs. 2a, d) y por medio de una ligera depresión en las isopletas del oxígeno (Fig. 2c) ; en la Sección VI, por una termoclina débil (Fig. 4a), una depresión en las isopletas del oxígeno (Fig. 4c), y depresiones en las isopletas de fosfato, nitrato y silicato (Figs. 4d, e, g) ; en la Sección VII, por una termoclina débil (Figs. 5a, d) y una depresión en las isopletas del oxígeno (Fig. 5c) ; en la Sección VIII por una termoclina ligeramente débil (Fig. 5d) y una depresión en las isopletas del oxígeno (Fig. 5c) ; y en las Secciones IX y X, por una temperatura superficial baja y una termoclina débil (Figs. 6a, d) y una depresión en las isopletas del oxígeno (Fig. 6c). Esta depresión en las isopletas del oxígeno fue señaladamente más ancha al este que en el oeste, un fenómeno que puede asociarse con la mezcla causada por la subcorriente que fluye hacia el este. El centro de la subcorriente conforme es indicado por la termoclina débil, disminuye en profundidad de oeste a este aproximadamente de 180 m a los 180° hasta cerca de 100 m a los 100°W.

Según las distribuciones areales de las variables biológicas (Figs. 7a, b, c), puede verse que la primera producción y la abundancia relativa de fitoplancton y zooplancton son altas cerca a la costa de Chile, y moderadamente altas cerca a los 40°S en el Agua Subantártica. Las Secciones II, III y IV (Figs. 3d, e, g) muestran que las concentraciones de nutrientes en la superficie son relativamente altas en estas dos áreas. En el Pacífico central del sur, sin embargo, la producción primaria y la cosecha estable son muy bajas, lo que es compatible con las concentraciones bajas de nutrientes en esta área (Sección II, Fig. 3). En la zona ecuatorial la abundancia de plancton y la producción primaria son altas en la mayor parte de la región oriental y disminuye hacia el oeste. Las Secciones Ecuatoriales VII, VIII, IX, X y I, muestran que la termoclina es poco profunda en el este y que se profundiza hacia el oeste. La alta productividad y la abundancia de plancton en el este puede estar relacionada con el rápido reabastecimiento de nutrientes facilitado por la termoclina de poca profundidad, y hacia el sur y al este de las Islas Galápagos puede también estar relacionada con aguas ricas en nutrientes originadas del afloramiento costanero. La coincidencia de zonas de producción y abundancia relativamente bajas de plancton, centralizadas a los 7°N entre los 115°W y los 100°W (Figs. 7a, b, c) puede estar relacionada con la Contracorriente Ecuatorial del Norte localizada en esta latitud (Secciones VIII, IX y X). La distribución de profundidad del disco Secchi (Fig. 7d), corresponde a la distribución de las variables biológicas, con el aparecimiento de un agua menos transparente en las áreas biológicamente ricas.

## LITERATURE CITED—BIBLIOGRAFIA CITADA

Bennett, E. B.

1963 An oceanographic atlas of the eastern tropical Pacific Ocean, based on data from EASTROPIC Expedition, October-December [in English and Spanish].
Inter-Amer. Trop. Tuna Comm., Bull., 8(2) :33-113.

Forsbergh, E. D. and J. Joseph

1964 Biological production in the eastern Pacific Ocean [in English and Spanish].
Inter-Amer. Trop. Tuna Comm., Bull., 8(9) :477-527.

Griffiths, R. C.

1963 Analysis of variance of zooplankton catches from Expedition TEMPO.
*In:* Scripps Inst. of Oceanogr. Ref. 63-22:12-13.

Japan Ministry of Agriculture and Forestry, Fishery Agency, Investigation Research Division, First Research Section

1964 Report of the research vessel *Shoyo Maru* [in Japanese] (Chosasen *Shoyo Maru* Hokokusho).
Mimeo., 465 p.

Knauss, J. A.

1960 Measurements of the Cromwell Current.
Deep-Sea Res., 6(4) :265-286.

McGill, D. A.

1961 The calculation of specific volume anomalies and interpolation for dynamic heights with the RECOMP II computer.
Woods Hole Oceanogr. Inst. Ref. 61-21.

Parsons, T. R. and J. D. H. Strickland

1963 Discussion of spectrophotometric determination of marine plant pigments, with revised equations for ascertaining chlorophylls and carotenoids.
J. Mar. Res., 21(3) :155-172.

Reid, J. L.

1959 Evidence of a South Equatorial Countercurrent in the Pacific Ocean.
Nature, 184(4681) :209-210.

Richards, F. A. with T. G. Thompson

1952 The estimation and characterization of plankton populations by pigment analysis. II. A spectrophotometric method for the estimation of plankton pigments.
J. Mar. Res., 11(2):156-172.

Steemann Nielsen, E.

1952 The use of radio-carbon ($C^{14}$) for measuring organic production in the sea.
J. Cons. Intern. Explor. Mer. 18(2):117-140.

Stefansson, U. and F. A. Richards

1963 Processes contributing to the nutrient distributions off the Columbia River and Strait of Juan de Fuca.
Limnol. Oceanogr., 8(4):394-410.

Strickland, J. D. H. and T. R. Parsons

1960 A manual of sea water analysis.
Bull. Fish. Res. Bd. Canada, No. 125, 185 p.

Truesdale, G. A., A. L. Downing and G. P. Lowden

1955 The solubility of oxygen in pure water and sea water.
J. Appl. Chem., 5(2):53-62.

U.S. Navy Hydrographic Office

1960 Manual for coding and punching oceanographic data on cards.
Special Publication 12, Part III, 122 p.

Wooster, W. S. and T. Cromwell

1958 An oceanographic description of the eastern tropical Pacific.
Bull. Scripps Inst. Oceanogr., 7(3):169-281.

______ and M. Gilmartin

1961 The Peru-Chile Undercurrent.
J. Mar. Res., 19(3):97-122.

______ and B. A. Taft

1958 On the reliability of field measurements of temperature and salinity in the ocean.
J. Mar. Res., 17:552-566.

Yentsch, C. S. and D. W. Menzel
1963 A method for the determination of phytoplankton chlorophyll and phaeophytin by fluorescence.
Deep-Sea Res., 10(3): 221-231.

# APPENDIX A—APENDICE A

## PHYSICAL AND CHEMICAL OBSERVATIONS—OBSERVACIONES FISICAS Y QUIMICAS

**Explanation of table headings**

**Explicación de los títulos de las tablas**

| | |
|---|---|
| Time | Local times of start and finish of hydrographic observations<br>Hora local del comienzo y de la terminación de las observaciones hidrográficas |
| D (m) | Secchi disc depth, meters<br>Profundidad del disco Secchi, metros |

**Observed and computed values at observed depths**

**Valores observados y calculados en las profundidades observadas**

| | |
|---|---|
| Z (m) | Sampling depth, meters<br>Profundidad del muestreo, metros |
| T (C) | *In situ* temperature, degrees Celsius<br>Temperatura *in situ*, centígrados |
| Cl (‰) | Chlorinity, grams per kilogram<br>Clorinidad, gramos por kilogramo |
| S (‰) | Salinity, grams per kilogram<br>Salinidad, gramos por kilogramo |
| $O_2$ (ml/L) | Dissolved oxygen concentration, milliliters per liter<br>Concentración de oxígeno disuelto, mililitros por litro |
| $\sigma_T$ (gm/L) | Potential density anomaly, grams per liter<br>Anomalía de densidad potencial, gramos por litro |
| $\delta_T$ (cl/T) | Thermosteric anomaly, centiliters per metric ton<br>Anomalía termostérica, centilitros por tonelada métrica |
| AOU (ml/L) | Apparent oxygen utilization (difference between equilibrium oxygen solubility and observed oxygen content), milliliters per liter<br>Utilización aparente de oxígeno (la diferencia entre la solubilidad equilibrada de oxígeno y el contenido de oxígeno observado) mililitros por litro |
| $PO_4$ ($\mu$g-at/L) | Inorganic phosphate-phosphorus concentration, microgram-atoms per liter<br>Concentración de fósforo inorgánico en forma de fosfato, microgramos-átomos por litro |
| $NO_3$ ($\mu$g-at/L) | Inorganic nitrate-nitrogen concentration, microgram-atoms per liter<br>Concentración de nitrógeno inorgánico en forma de nitrato, microgramos-átomos por litro |
| $SiO_4$ ($\mu$g-at/L) | Reactive silicate-silicon concentration, microgram-atoms per liter<br>Concentración de silicio reactivo en forma de silicato, miligramos-átomos por litro |
| $NO_2$ ($\mu$g-at/L) | Inorganic nitrite-nitrogen concentration, microgram-atoms per liter<br>Concentración de nitrógeno inorgánico en forma de nitrito, miligramos-átomos por litro |

**Interpolated and computed values at standard depths**

**Valores interpolados y calculados a profundidades estándar**

| | |
|---|---|
| Z (m) | Standard depth, meters<br>Profundidad estándar, metros |
| T (C) | Interpolated temperature, degrees Celsius<br>Temperatura interpolada, centígrados |

## APPENDIX A (Continued)

| | |
|---|---|
| Cl (‰) | Interpolated chlorinity, grams per kilogram<br>Clorinidad interpolada, gramos por kilogramo |
| S (‰) | Interpolated salinity, grams per kilogram<br>Salinidad interpolada, gramos por kilogramo |
| $\sigma_T$ (gm/L) | Interpolated potential density anomaly, grams per liter<br>Anomalía interpolada de densidad potencial, gramos por litro |
| $\delta_T$ (cl/T) | Interpolated thermosteric anomaly, centiliters per metric ton<br>Anomalía termostérica interpolada, centilitros por tonelada métrica |
| $\delta$ (cl/T) | Interpolated specific volume anomaly, centiliters per metric ton<br>Anomalía interpolada del volumen específico, centilitros por tonelada métrica |
| $\Delta D_{Z/O}$ (dyn m) | Dynamic height between the interpolated depth and the sea surface, dynamic meters<br>Altitud dinámica entre la profundidad interpolada y la superficie del mar, metros dinámicos |
| $\Delta D_{Z/Z}$ (dyn m) | Dynamic height between the interpolated depth and the maximum interpolated depth, dynamic meters<br>Altitud dinámica entre la profundidad interpolada y la profundidad máxima interpolada, metros dinámicos |
| $Q_Z$ (m-dyn m) | Transport function between the interpolated depth and the maximum interpolated depth, meters-dynamic meters<br>Función de transporte entre la profundidad interpolada y la profundidad máxima interpolada, metros-metros dinámicos |

**Missing data—Datos que faltan**

| | |
|---|---|
| 999.00 | No observation of either temperature, chlorinity or dissolved oxygen<br>No hubo observaciones de temperatura, clorinidad o oxígeno disuelto |
| —0 | No observation—No hubo observación |
| 0 | Observation was made and its value is zero<br>Se hizo observación y su valor es cero |

**Explanation of notes**

**Explicación de las notas**

a) Questionable value 19.18‰—Valor cuestionable de 19.18‰

b) Questionable value 3.32 ml/L—Valor cuestionable de 3.32 ml/L

c) All chlorinities were questionable. Observed values were:
Todas las clorinidades fueron cuestionables. Los valores observados fueron:
0 m = 19.10‰; 49 m = 19.76‰; 74 m = 19.55‰; 99 m = 19.42‰; 148 m = 19.39‰; 212 m = 19.33‰; 300 m = 19.29‰; 395 m = 19.21‰; 562 m = 19.16‰

d) All chlorinities were questionable. Observed values were:
Todas las clorinidades fueron cuestionables. Los valores observados fueron:
0 m = 19.81‰; 48 m = 19.76‰; 73 m = 19.73‰; 98 m = 19.63‰; 147 m = 19.60‰; 200 m = 19.18‰; 295 m = 19.12‰; 383 m = 19.10‰; 575 m = 19.06‰

e) Questionable value, 4.72 ml/L—Valor cuestionable de 4.72 ml/L

f) Extrapolated value used instead of questionable value of 18.73‰
Se usó el valor extrapolado en vez del valor cuestionable de 18.73‰

g) Questionable value 19.41‰—Valor cuestionable de 19.41‰

h) Questionable value 3.86 ml/L—Valor cuestionable de 3.86 ml/L

i) Extrapolated value used in place of missing datum
Se usó el valor extrapolado en vez del dato que falta

j) Extrapolated value used instead of questionable value of 19.36‰
Se usó el valor extrapolado en vez del valor cuestionable de 19.36‰

k) Extrapolated value used in place of missing datum
Se usó el valor extrapolado en vez del dato que falta

H 001

| STATION | DATE | TIME | LATITUDE | LONGITUDE | D |
|---|---|---|---|---|---|
| H 001 | OCT 6, 1963 | 1220-1320 | 10° 14.1'N | 172° 50.0'E | 35 |

OBSERVED AND COMPUTED VALUES AT OBSERVED DEPTHS

| Z (m) | T (°C) | Cl (‰) | S (‰) | $O_2$ (ml/L) | $\sigma_T$ (gm/L) | $\delta_T$ (cl/L) | AOU (ml/L) | $PO_4$ (µg at./L) | $NO_3$ (µg at./L) | $SiO_4$ (µg at./L) | $NO_2$ (µg at./L) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 0 | 29.10 | 18.90 | 34.14 | 4.92 | 21.41 | 639.6 | -.57 | -0 | -0 | -0 | -0 |
| 24 | 29.20 | 18.95 | 34.23 | 4.46 | 21.44 | 636.3 | -.12 | -0 | -0 | -0 | -0 |
| 49 | 28.95 | 18.92 | 34.18 | 4.45 | 21.49 | 632.2 | -.09 | -0 | -0 | -0 | -0 |
| 74 | 26.05 | 19.11 | 34.52 | 4.47 | 22.68 | 518.0 | .08 | -0 | -0 | -0 | -0 |
| 97 | 22.10 | 19.34 | 34.94 | 4.58 | 24.16 | 376.4 | .26 | -0 | -0 | -0 | -0 |
| 146 | 14.70 | 19.09 | 34.49 | 3.21 | 25.66 | 233.8 | 2.35 | -0 | -0 | -0 | -0 |
| 203 | 10.01 | 19.14 | 34.58 | .90 | 26.64 | 140.8 | 5.24 | -0 | -0 | -0 | -0 |
| 305 | 999.00 | 19.19 | 34.67 | .91 | 999.00 | 999.0 | 999.00 | -0 | -0 | -0 | -0 |
| 410 | 8.54 | 19.17 | 34.63 | .90 | 26.92 | 114.0 | 5.44 | -0 | -0 | -0 | -0 |
| 595 | 6.28 | 19.14 | 34.58 | .98 | 27.20 | 87.3 | 5.72 | -0 | -0 | -0 | -0 |

INTERPOLATED AND COMPUTED VALUES AT STANDARD DEPTHS

| Z (m) | T (°C) | Cl (‰) | S (‰) | $\sigma_T$ (gm/L) | $\delta_T$ (cl/T) | $\delta$ (cl/T) | $\Delta D_{Z/0}$ (dyn m) | $\Delta D_{Z/Z MAX}$ (dyn m) | $Q_Z$ (m-dynm) |
|---|---|---|---|---|---|---|---|---|---|
| 0 | 29.10 | 18.90 | 34.14 | 21.41 | 639.6 | 639.7 | 0 | 1.302 | 249.4 |
| 10 | 29.17 | 18.92 | 34.19 | 21.42 | 638.7 | 639.2 | .064 | 1.238 | 236.7 |
| 20 | 29.19 | 18.94 | 34.22 | 21.43 | 637.2 | 638.2 | .128 | 1.174 | 224.7 |
| 30 | 29.16 | 18.95 | 34.23 | 21.45 | 635.5 | 636.9 | .192 | 1.111 | 213.3 |
| 50 | 28.88 | 18.92 | 34.19 | 21.51 | 629.7 | 631.9 | .318 | .984 | 192.3 |
| 75 | 25.91 | 19.12 | 34.54 | 22.73 | 512.9 | 516.0 | .462 | .840 | 169.5 |
| 100 | 21.55 | 19.31 | 34.88 | 24.27 | 365.8 | 369.6 | .573 | .730 | 149.9 |
| 150 | 14.32 | 19.09 | 34.48 | 25.74 | 226.2 | 230.6 | .723 | .580 | 117.2 |
| 200 | 10.22 | 19.13 | 34.57 | 26.59 | 145.0 | 149.6 | .818 | .485 | 90.6 |
| 250 | 9.57 | 19.15 | 34.59 | 26.72 | 132.9 | 138.3 | .890 | .413 | 68.1 |
| 300 | 9.19 | 19.15 | 34.60 | 26.80 | 125.9 | 132.2 | .957 | .345 | 49.2 |
| 400 | 8.59 | 19.17 | 34.63 | 26.91 | 115.0 | 122.8 | 1.085 | .217 | 21.1 |
| 500 | 7.34 | 19.15 | 34.59 | 27.07 | 99.8 | 108.3 | 1.200 | .102 | 5.1 |
| 600 | 6.23 | 19.14 | 34.58 | 27.21 | 86.7 | 95.6 | 1.302 | 0 | 0 |

H 004

| STATION | DATE | TIME | LATITUDE | LONGITUDE | D |
|---|---|---|---|---|---|
| H 004 | OCT 7, 1963 | 1220-1318 | 06°49.0'N | 175°15.0'E | 43 |

OBSERVED AND COMPUTED VALUES AT OBSERVED DEPTHS

| Z (m) | T (°C) | Cl (‰) | S (‰) | $O_2$ (ml/L) | $\sigma_T$ (gm/L) | $\delta_T$ (cl/L) | AOU (ml/L) | $PO_4$ (µg at./L) | $NO_3$ (µg at./L) | $SiO_4$ (µg at./L) | $NO_2$ (µg at./L) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 0 | 30.10 | 18.73 | 33.84 | 4.42 | 20.84 | 694.1 | -.13 | -0 | -0 | -0 | -0 |
| 25 | 29.42 | 18.70 | 33.78 | 4.39 | 21.03 | 675.8 | -.05 | -0 | -0 | -0 | -0 |
| 50 | 28.91 | 18.85 | 34.05 | 4.54 | 21.41 | 640.0 | -.17 | -0 | -0 | -0 | -0 |
| 75 | 25.49 | 19.19 | 34.67 | 4.81 | 22.96 | 491.0 | -.22 | -0 | -0 | -0 | -0 |
| 100 | 20.54 | 19.26 | 34.79 | 4.22 | 24.48 | 346.1 | .76 | -0 | -0 | -0 | -0 |
| 150 | 14.80 | 19.15 | 34.60 | 2.68 | 25.72 | 227.9 | 2.87 | -0 | -0 | -0 | -0 |
| 216 | 10.61 | 19.19 | 34.67 | .81 | 26.61 | 144.0 | 5.24 | -0 | -0 | -0 | -0 |
| 272 | 9.45 | 19.18 | 34.65 | .80 | 26.79 | 126.5 | 5.41 | -0 | -0 | -0 | -0 |
| 390 | 8.44 | 19.18 | 34.65 | 1.92 | 26.95 | 111.2 | 4.44 | -0 | -0 | -0 | -0 |

INTERPOLATED AND COMPUTED VALUES AT STANDARD DEPTHS

| Z (m) | T (°C) | Cl (‰) | S (‰) | $\sigma_T$ (gm/L) | $\delta_T$ (cl/T) | $\delta$ (cl/T) | $\Delta D_{Z/0}$ (dyn m) | $\Delta D_{Z/Z MAX}$ (dyn m) | $Q_Z$ (m-dynm) |
|---|---|---|---|---|---|---|---|---|---|
| 0 | 30.10 | 18.73 | 33.84 | 20.84 | 694.1 | 694.2 | 0 | 1.096 | 140.7 |
| 10 | 29.93 | 18.72 | 33.82 | 20.89 | 689.5 | 690.0 | .069 | 1.027 | 130.1 |
| 20 | 29.65 | 18.71 | 33.80 | 20.97 | 681.9 | 682.9 | .138 | .958 | 120.2 |
| 30 | 29.34 | 18.72 | 33.82 | 21.08 | 670.7 | 672.1 | .206 | .891 | 111.0 |
| 50 | 28.91 | 18.85 | 34.05 | 21.40 | 640.0 | 642.2 | .337 | .759 | 94.5 |
| 75 | 25.49 | 19.19 | 34.67 | 22.96 | 491.0 | 494.1 | .479 | .617 | 77.3 |
| 100 | 20.54 | 19.26 | 34.79 | 24.48 | 346.1 | 349.8 | .585 | .512 | 63.1 |
| 150 | 14.80 | 19.15 | 34.60 | 25.72 | 227.9 | 232.4 | .730 | .366 | 41.2 |
| 200 | 11.50 | 19.17 | 34.63 | 26.42 | 161.8 | 166.8 | .830 | .266 | 25.4 |
| 250 | 9.87 | 19.18 | 34.65 | 26.72 | 132.9 | 138.5 | .906 | .190 | 14.0 |
| 300 | 9.18 | 19.18 | 34.65 | 26.83 | 122.4 | 128.6 | .973 | .123 | 6.2 |
| 400 | 8.37 | 19.18 | 34.65 | 26.96 | 110.1 | 117.8 | 1.096 | 0 | 0 |

| STATION | DATE | TIME | LATITUDE | LONGITUDE | D |
|---|---|---|---|---|---|
| H 007 | OCT 8, 1963 | 1220-1310 | 03°09.5'N | 177°48.0'E | 38 |

OBSERVED AND COMPUTED VALUES AT OBSERVED DEPTHS

| Z (m) | T (°C) | Cl (‰) | S (‰) | $O_2$ (ml/L) | $\sigma_T$ (gm/L) | $\delta_T$ (cl/L) | AOU (ml/L) | $PO_4$ | $NO_3$ | $SiO_4$ | $NO_2$ |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | (μg at./L) | | | |
| 0 | 30.70 | 19.26 | 34.79 | 4.43 | 21.35 | 645.2 | -.20 | -0 | -0 | -0 | -0 |
| 24 | 29.93 | 19.27 | 34.81 | 4.45 | 21.63 | 618.5 | -.17 | -0 | -0 | -0 | -0 |
| 48 | 29.85 | 19.52 | 35.26 | 4.48 | 22.00 | 583.5 | -.21 | -0 | -0 | -0 | -0 |
| 72 | 29.61 | 19.52 | 35.26 | 4.43 | 22.08 | 575.7 | -.14 | -0 | -0 | -0 | -0 |
| 96 | 29.15 | 19.59 | 35.39 | 4.30 | 22.33 | 551.7 | .01 | -0 | -0 | -0 | -0 |
| 144 | 26.15 | 19.60 | 35.41 | 3.28 | 23.32 | 457.3 | 1.24 | -0 | -0 | -0 | -0 |
| 243 | 11.45 | 19.28 | 34.83 | 2.48 | 26.58 | 146.5 | 3.46 | -0 | -0 | -0 | -0 |
| 355 | 10.08 | 19.24 | 34.76 | 1.58 | 26.77 | 128.6 | 4.54 | -0 | -0 | -0 | -0 |
| 439 | 8.64 | 19.21 | 34.70 | 2.46 | 26.96 | 110.1 | 3.87 | -0 | -0 | -0 | -0 |
| 639 | 7.02 | 19.18 | 34.65 | 2.08 | 27.16 | 91.4 | 4.50 | -0 | -0 | -0 | -0 |

INTERPOLATED AND COMPUTED VALUES AT STANDARD DEPTHS

| Z (m) | T (°C) | Cl (‰) | S (‰) | $\sigma_T$ (gm/L) | $\delta_T$ (cl/T) | $\delta$ (cl/T) | $\Delta D_{Z/0}$ (dyn m) | $\Delta D_{Z/Z MAX}$ (dyn m) | $Q_Z$ (m-dynm) |
|---|---|---|---|---|---|---|---|---|---|
| 0 | 30.70 | 19.26 | 34.79 | 21.35 | 645.2 | 645.3 | 0 | 1.676 | 364.0 |
| 10 | 30.50 | 19.26 | 34.80 | 21.42 | 638.2 | 638.7 | .064 | 1.612 | 347.5 |
| 20 | 30.15 | 19.27 | 34.81 | 21.55 | 626.1 | 627.1 | .127 | 1.549 | 331.7 |
| 30 | 29.91 | 19.32 | 34.90 | 21.70 | 611.8 | 613.1 | .190 | 1.487 | 316.5 |
| 50 | 29.83 | 19.52 | 35.26 | 22.00 | 582.9 | 585.1 | .309 | 1.367 | 288.0 |
| 75 | 29.56 | 19.53 | 35.28 | 22.10 | 573.0 | 576.3 | .455 | 1.222 | 255.6 |
| 100 | 28.98 | 19.59 | 35.40 | 22.39 | 545.7 | 550.0 | .595 | 1.081 | 226.8 |
| 150 | 25.51 | 19.57 | 35.35 | 23.47 | 442.3 | 448.4 | .845 | .831 | 179.0 |
| 200 | 17.73 | 19.25 | 34.77 | 25.18 | 279.4 | 286.1 | 1.028 | .648 | 142.1 |
| 250 | 11.35 | 19.28 | 34.82 | 26.59 | 145.2 | 151.3 | 1.138 | .538 | 112.4 |
| 300 | 10.69 | 19.26 | 34.79 | 26.68 | 136.6 | 143.6 | 1.212 | .465 | 87.3 |
| 400 | 9.27 | 19.22 | 34.72 | 26.88 | 118.2 | 126.5 | 1.347 | .330 | 47.6 |
| 500 | 8.08 | 19.20 | 34.68 | 27.03 | 103.6 | 112.9 | 1.466 | .210 | 20.6 |
| 600 | 7.29 | 19.18 | 34.66 | 27.13 | 94.6 | 104.7 | 1.575 | .101 | 5.1 |
| 700 | 6.63 | 19.18 | 34.64 | 27.21 | 86.9 | 97.7 | 1.676 | 0 | 0 |

| STATION | DATE | TIME | LATITUDE | LONGITUDE | D |
|---|---|---|---|---|---|
| H 010 | OCT 9, 1963 | 1200-1300 | 00°18.0'S | 179°47.0'E | 30 |

OBSERVED AND COMPUTED VALUES AT OBSERVED DEPTHS

| Z (m) | T (°C) | Cl (‰) | S (‰) | $O_2$ (ml/L) | $\sigma_T$ (gm/L) | $\delta_T$ (cl/L) | AOU (ml/L) | $PO_4$ | $NO_3$ | $SiO_4$ | $NO_2$ |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | (μg at./L) | | | |
| 0 | 29.30 | 19.44 | 35.12 | 4.47 | 22.07 | 576.0 | -.16 | -0 | -0 | -0 | -0 |
| 22 | 29.26 | 19.46 | 35.16 | 4.54 | 22.11 | 572.1 | -.23 | -0 | -0 | -0 | -0 |
| 43 | 28.88 | 19.51 | 35.25 | 4.65 | 22.31 | 553.4 | -.32 | -0 | -0 | -0 | -0 |
| 65 | 28.74 | 19.56 | 35.34 | 4.31 | 22.42 | 542.5 | .03 | -0 | -0 | -0 | -0 |
| 87 | 28.52 | 19.60 | 35.41 | 4.25 | 22.55 | 530.3 | .10 | -0 | -0 | -0 | -0 |
| 130 | 28.17 | 19.63 | 35.46 | 4.10 | 22.71 | 515.4 | .28 | -0 | -0 | -0 | -0 |
| 289 | 11.67 | 19.27 | 34.81 | 2.44 | 26.52 | 151.8 | 3.47 | -0 | -0 | -0 | -0 |
| 390 | 9.05 | 19.18 | 34.65 | 1.13 | 26.86 | 120.3 | 5.14 | -0 | -0 | -0 | -0 |
| 511 | 8.16 | 19.20 | 34.69 | 1.08 | 27.02 | 104.4 | 5.32 | -0 | -0 | -0 | -0 |
| 698 | 6.52 | 19.11 | 34.52 | 1.59 | 27.13 | 94.4 | 5.07 | -0 | -0 | -0 | -0 |

INTERPOLATED AND COMPUTED VALUES AT STANDARD DEPTHS

| Z (m) | T (°C) | Cl (‰) | S (‰) | $\sigma_T$ (gm/L) | $\delta_T$ (cl/T) | $\delta$ (cl/T) | $\Delta D_{Z/0}$ (dyn m) | $\Delta D_{Z/Z MAX}$ (dyn m) | $Q_Z$ (m-dynm) |
|---|---|---|---|---|---|---|---|---|---|
| 0 | 29.30 | 19.44 | 35.12 | 22.07 | 576.0 | 576.1 | 0 | 1.760 | 394.0 |
| 10 | 29.29 | 19.45 | 35.13 | 22.08 | 574.9 | 575.4 | .058 | 1.702 | 376.7 |
| 20 | 29.27 | 19.46 | 35.15 | 22.11 | 572.8 | 573.7 | .115 | 1.645 | 360.0 |
| 30 | 29.16 | 19.47 | 35.18 | 22.16 | 567.2 | 568.5 | .172 | 1.588 | 343.8 |
| 50 | 28.64 | 19.52 | 35.27 | 22.34 | 550.4 | 552.6 | .284 | 1.476 | 313.2 |
| 75 | 28.65 | 19.58 | 35.37 | 22.48 | 537.4 | 540.6 | .421 | 1.339 | 278.0 |
| 100 | 28.43 | 19.61 | 35.42 | 22.59 | 526.2 | 530.5 | .555 | 1.205 | 246.2 |
| 150 | 26.86 | 19.56 | 35.34 | 23.04 | 483.8 | 490.0 | .810 | .950 | 192.3 |
| 200 | 21.53 | 19.30 | 34.87 | 24.27 | 366.0 | 373.4 | 1.026 | .734 | 150.2 |
| 250 | 15.39 | 19.20 | 34.68 | 25.66 | 233.7 | 241.3 | 1.179 | .581 | 117.3 |
| 300 | 11.34 | 19.26 | 34.79 | 26.56 | 147.8 | 155.2 | 1.279 | .482 | 90.8 |
| 400 | 8.97 | 19.18 | 34.65 | 26.87 | 118.8 | 126.9 | 1.420 | .340 | 49.7 |
| 500 | 8.23 | 19.20 | 34.68 | 27.01 | 105.7 | 115.1 | 1.541 | .219 | 21.7 |
| 600 | 7.32 | 19.15 | 34.60 | 27.08 | 99.3 | 109.4 | 1.653 | .107 | 5.4 |
| 700 | 6.50 | 19.11 | 34.52 | 27.13 | 94.3 | 104.9 | 1.760 | 0 | 0 |

H 013

| STATION | DATE | TIME | LATITUDE | LONGITUDE | D |
|---|---|---|---|---|---|
| H 013 | OCT 9, 1963 | 1230-1310 | 03° 18.8'S | 178° 14.0'W | 31 |

OBSERVED AND COMPUTED VALUES AT OBSERVED DEPTHS

| Z (m) | T (°C) | Cl (‰) | S (‰) | $O_2$ (ml/L) | $\sigma_T$ (gm/L) | $\delta_T$ (cl/L) | AOU (ml/L) | $PO_4$ (μg at./L) | $NO_3$ (μg at./L) | $SiO_4$ (μg at./L) | $NO_2$ (μg at./L) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 0 | 29.55 | 19.56 | 35.34 | 4.65 | 22.15 | 568.5 | -.36 | -0 | -0 | -0 | -0 |
| 24 | 29.64 | 19.55 | 35.32 | 4.52 | 22.11 | 572.8 | -.24 | -0 | -0 | -0 | -0 |
| 47 | 29.45 | 19.56 | 35.34 | 4.50 | 22.19 | 565.3 | -.21 | -0 | -0 | -0 | -0 |
| 70 | 29.17 | 19.69 | 35.57 | 4.42 | 22.46 | 539.4 | -.11 | -0 | -0 | -0 | -0 |
| 94 | 28.97 | 19.69 | 35.57 | 4.46 | 22.52 | 533.0 | -.14 | -0 | -0 | -0 | -0 |
| 141 | 27.78 | 19.84 | 35.84 | 3.79 | 23.12 | 475.9 | .60 | -0 | -0 | -0 | -0 |
| 214 | 18.53 | 19.68 | 35.55 | 2.72 | 25.58 | 241.4 | 2.41 | -0 | -0 | -0 | -0 |
| 304 | 10.29 | 19.30 | 34.87 | 2.54 | 26.82 | 124.0 | 3.55 | -0 | -0 | -0 | -0 |
| 390 | 9.18 | 19.23 | 34.74 | 1.82 | 26.91 | 115.6 | 4.43 | -0 | -0 | -0 | -0 |
| 530 | 7.62 | 19.20 | 34.69 | 2.23 | 27.10 | 96.8 | 4.25 | -0 | -0 | -0 | -0 |

INTERPOLATED AND COMPUTED VALUES AT STANDARD DEPTHS

| Z (m) | T (°C) | Cl (‰) | S (‰) | $\sigma_T$ (gm/L) | $\delta_T$ (cl/T) | $\delta$ (cl/T) | $\Delta D_{Z/0}$ (dyn m) | $\Delta D_{Z/Z\,MAX}$ (dyn m) | $Q_Z$ (m-dynm) |
|---|---|---|---|---|---|---|---|---|---|
| 0 | 29.55 | 19.56 | 35.34 | 22.15 | 568.5 | 568.7 | 0 | 1.443 | 238.9 |
| 10 | 29.62 | 19.55 | 35.32 | 22.12 | 571.7 | 572.2 | .057 | 1.386 | 224.7 |
| 20 | 29.64 | 19.55 | 35.32 | 22.11 | 572.5 | 573.5 | .114 | 1.329 | 211.1 |
| 30 | 29.60 | 19.55 | 35.32 | 22.12 | 571.3 | 572.7 | .172 | 1.272 | 198.1 |
| 50 | 29.42 | 19.57 | 35.35 | 22.21 | 563.0 | 565.2 | .285 | 1.158 | 173.8 |
| 75 | 29.13 | 19.69 | 35.57 | 22.47 | 538.2 | 541.4 | .424 | 1.019 | 146.6 |
| 100 | 28.86 | 19.70 | 35.60 | 22.58 | 527.6 | 531.8 | .558 | .885 | 122.8 |
| 150 | 26.37 | 19.82 | 35.81 | 23.36 | 453.3 | 459.5 | .806 | .637 | 84.8 |
| 200 | 20.20 | 19.67 | 35.54 | 25.13 | 283.9 | 291.1 | .993 | .450 | 57.6 |
| 250 | 14.88 | 19.45 | 35.14 | 26.13 | 189.5 | 196.9 | 1.115 | .328 | 38.1 |
| 300 | 10.60 | 19.31 | 34.88 | 26.77 | 128.5 | 135.5 | 1.198 | .245 | 23.8 |
| 400 | 9.05 | 19.23 | 34.73 | 26.92 | 114.1 | 122.2 | 1.327 | .116 | 5.8 |
| 500 | 7.92 | 19.20 | 34.69 | 27.06 | 100.4 | 109.5 | 1.443 | 0 | 0 |

H 016

| STATION | DATE | TIME | LATITUDE | LONGITUDE | D |
|---|---|---|---|---|---|
| H 016 | OCT 10, 1963 | 1230-1315 | 06° 49.7'S | 176° 05.0'W | 25 |

OBSERVED AND COMPUTED VALUES AT OBSERVED DEPTHS

| Z (m) | T (°C) | Cl (‰) | S (‰) | $O_2$ (ml/L) | $\sigma_T$ (gm/L) | $\delta_T$ (cl/L) | AOU (ml/L) | $PO_4$ (μg at./L) | $NO_3$ (μg at./L) | $SiO_4$ (μg at./L) | $NO_2$ (μg at./L) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 0 | 29.60 | 19.66 | 35.52 | 4.56 | 22.27 | 557.2 | -.28 | -0 | -0 | -0 | -0 |
| 25 | 29.60 | 19.64 | 35.48 | 4.46 | 22.24 | 559.8 | -.18 | -0 | -0 | -0 | -0 |
| 49 | 29.42 | 19.68 | 35.55 | 4.49 | 22.36 | 548.8 | -.20 | -0 | -0 | -0 | -0 |
| 74 | 29.33 | 19.69 | 35.57 | 4.17 | 22.40 | 544.6 | .13 | -0 | -0 | -0 | -0 |
| 99 | 29.09 | 19.69 | 35.57 | 4.33 | 22.48 | 536.8 | -.02 | -0 | -0 | -0 | -0 |
| 148 | 26.85 | 19.87 | 35.90 | 3.59 | 23.46 | 443.4 | .87 | -0 | -0 | -0 | -0 |
| 210 | 22.07 | 19.93 | 36.00 | 3.53 | 24.98 | 298.6 | 1.26 | -0 | -0 | -0 | -0 |
| 311 | 12.24 | 19.35 | 34.96 | 1.89 | 26.53 | 151.5 | 3.94 | -0 | -0 | -0 | -0 |
| 394 | 9.14 | 19.26 | 34.79 | 2.32 | 26.95 | 111.0 | 3.93 | -0 | -0 | -0 | -0 |
| 594 | 6.49 | 19.14 | 34.58 | 2.85 | 27.18 | 90.0 | 3.81 | -0 | -0 | -0 | -0 |

INTERPOLATED AND COMPUTED VALUES AT STANDARD DEPTHS

| Z (m) | T (°C) | Cl (‰) | S (‰) | $\sigma_T$ (gm/L) | $\delta_T$ (cl/T) | $\delta$ (cl/T) | $\Delta D_{Z/0}$ (dyn m) | $\Delta D_{Z/Z\,MAX}$ (dyn m) | $Q_Z$ (m-dynm) |
|---|---|---|---|---|---|---|---|---|---|
| 0 | 29.60 | 19.66 | 35.52 | 22.27 | 557.2 | 557.3 | 0 | 1.610 | 313.5 |
| 10 | 29.60 | 19.65 | 35.49 | 22.25 | 559.1 | 559.2 | .056 | 1.554 | 297.7 |
| 20 | 29.60 | 19.64 | 35.48 | 22.24 | 559.6 | 559.7 | .112 | 1.498 | 282.4 |
| 30 | 29.58 | 19.65 | 35.49 | 22.26 | 558.1 | 559.5 | .168 | 1.442 | 267.7 |
| 50 | 29.42 | 19.68 | 35.55 | 22.36 | 548.6 | 550.8 | .279 | 1.331 | 240.0 |
| 75 | 29.32 | 19.69 | 35.57 | 22.40 | 544.3 | 547.6 | .416 | 1.194 | 208.4 |
| 100 | 29.06 | 19.69 | 35.57 | 22.49 | 535.7 | 539.9 | .552 | 1.058 | 180.3 |
| 150 | 26.74 | 19.67 | 35.90 | 23.50 | 440.0 | 446.1 | .799 | .811 | 133.6 |
| 200 | 23.12 | 19.92 | 35.98 | 24.66 | 328.9 | 336.5 | .994 | .615 | 97.9 |
| 250 | 18.37 | 19.65 | 35.49 | 25.58 | 241.8 | 250.3 | 1.141 | .469 | 70.8 |
| 300 | 13.24 | 19.38 | 35.01 | 26.37 | 166.4 | 174.6 | 1.247 | .363 | 50.0 |
| 400 | 9.04 | 19.25 | 34.78 | 26.96 | 110.2 | 118.4 | 1.394 | .216 | 21.1 |
| 500 | 7.60 | 19.18 | 34.66 | 27.08 | 98.8 | 107.6 | 1.507 | .103 | 5.2 |
| 600 | 6.43 | 19.14 | 34.57 | 27.18 | 89.4 | 98.5 | 1.610 | 0 | 0 |

| STATION | DATE | TIME | LATITUDE | LONGITUDE | D |
|---|---|---|---|---|---|
| H 019 | OCT 11, 1963 | 1220-1345 | 10° 23.7'S | 173° 49.2'W | 40 |

OBSERVED AND COMPUTED VALUES AT OBSERVED DEPTHS

| Z (m) | T (°C) | Cl (‰) | S (‰) | $O_2$ (ml/L) | $\sigma_T$ (gm/L) | $\delta_T$ (cl/L) | AOU (ml/L) | $PO_4$ (µg at./L) | $NO_3$ (µg at./L) | $SiO_4$ (µg at./L) | $NO_2$ (µg at./L) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 0 | 29.10 | 19.66 | 35.52 | 4.42 | 22.44 | 541.0 | -.11 | -0 | -0 | -0 | -0 |
| 25 | 28.50 | 19.81 | 35.79 | 4.47 | 22.84 | 502.5 | -.13 | -0 | -0 | -0 | -0 |
| 50 | 28.14 | 19.75 | 35.68 | 4.47 | 22.86 | 498.9 | -.10 | -0 | -0 | -0 | -0 |
| 75 | 28.04 | 19.75 | 35.68 | 4.18 | 22.91 | 495.7 | .20 | -0 | -0 | -0 | -0 |
| 100 | 28.04 | 19.82 | 35.81 | 4.38 | 23.01 | 486.7 | -.00 | -0 | -0 | -0 | -0 |
| 150 | 24.87 | 999.00 | 999.00 | 3.56 | 999.00 | 999.0 | 999.00 | -0 | -0 | -0 | -0 |
| 194 | 20.53 | 19.82 | 35.81 | 3.62 | 25.25 | 272.6 | 1.32 | -0 | -0 | -0 | -0 |
| 319 | 13.80 | 19.42 | 35.08 | 2.85 | 26.31 | 172.0 | 2.79 | -0 | -0 | -0 | -0 |
| 404 | 9.64 | 19.19 | 34.67 | 2.59 | 26.77 | 128.2 | 3.60 | -0 | -0 | -0 | -0 |
| 598 | 6.26 | 19.12 | 34.54 | 2.97 | 27.18 | 89.8 | 3.73 | -0 | -0 | -0 | -0 |

INTERPOLATED AND COMPUTED VALUES AT STANDARD DEPTHS

| Z (m) | T (°C) | Cl (‰) | S (‰) | $\sigma_T$ (gm/L) | $\delta_T$ (cl/T) | $\delta$ (cl/T) | $\Delta D_{Z/0}$ (dyn m) | $\Delta D_{Z/Z\,MAX}$ (dyn m) | $Q_Z$ (m-dyn m) |
|---|---|---|---|---|---|---|---|---|---|
| 0 | 29.10 | 19.66 | 35.52 | 22.44 | 541.0 | 541.2 | 0 | 1.531 | 314.4 |
| 10 | 28.95 | 19.70 | 35.58 | 22.54 | 531.4 | 531.9 | .054 | 1.477 | 299.3 |
| 20 | 28.70 | 19.76 | 35.70 | 22.71 | 515.3 | 516.3 | .106 | 1.425 | 284.8 |
| 30 | 28.44 | 19.80 | 35.77 | 22.85 | 501.8 | 503.1 | .157 | 1.374 | 270.8 |
| 50 | 28.14 | 19.75 | 35.68 | 22.88 | 498.9 | 501.1 | .257 | 1.274 | 244.3 |
| 75 | 28.04 | 19.75 | 35.68 | 22.91 | 495.7 | 498.9 | .382 | 1.149 | 214.1 |
| 100 | 28.04 | 19.82 | 35.80 | 23.01 | 486.7 | 490.9 | .506 | 1.025 | 186.9 |
| 150 | 24.87 | 19.77 | 35.72 | 23.95 | 397.0 | 403.0 | .730 | .801 | 141.2 |
| 200 | 20.12 | 19.79 | 35.75 | 25.32 | 266.5 | 273.7 | .899 | .632 | 105.4 |
| 250 | 17.10 | 19.58 | 35.37 | 25.79 | 221.4 | 229.5 | 1.025 | .506 | 76.9 |
| 300 | 14.63 | 19.45 | 35.14 | 26.18 | 184.5 | 193.2 | 1.130 | .401 | 54.2 |
| 400 | 9.82 | 19.20 | 34.68 | 26.75 | 130.0 | 138.7 | 1.296 | .235 | 22.5 |
| 500 | 7.80 | 19.14 | 34.58 | 26.99 | 107.3 | 116.3 | 1.424 | .107 | 5.4 |
| 600 | 6.23 | 19.12 | 34.54 | 27.18 | 89.4 | 98.3 | 1.531 | 0 | 0 |

| STATION | DATE | TIME | LATITUDE | LONGITUDE | D |
|---|---|---|---|---|---|
| H 022 | OCT 12, 1963 | 1225-1310 | 13° 42.2'S | 171° 13.4'W | 38 |

OBSERVED AND COMPUTED VALUES AT OBSERVED DEPTHS

| Z (m) | T (°C) | Cl (‰) | S (‰) | $O_2$ (ml/L) | $\sigma_T$ (gm/L) | $\delta_T$ (cl/L) | AOU (ml/L) | $PO_4$ (µg at./L) | $NO_3$ (µg at./L) | $SiO_4$ (µg at./L) | $NO_2$ (µg at./L) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 0 | 28.90 | 19.81 | 35.79 | 4.38 | 22.71 | 515.2 | -.06 | -0 | -0 | -0 | -0 |
| 25 | 27.90 | 19.78 | 35.73 | 4.44 | 23.00 | 487.5 | -.05 | -0 | -0 | -0 | -0 |
| 50 | 27.71 | 19.79 | 35.75 | 4.50 | 23.08 | 480.2 | -.10 | -0 | -0 | -0 | -0 |
| 75 | 27.54 | 19.79 | 35.75 | 4.42 | 23.13 | 475.0 | -.01 | -0 | -0 | -0 | -0 |
| 100 | 27.38 | 19.76 | 35.70 | 3.94 | 23.14 | 473.9 | .48 | -0 | -0 | -0 | -0 |
| 150 | 25.36 | 20.06 | 36.24 | 4.47 | 24.19 | 374.2 | .08 | -0 | -0 | -0 | -0 |
| 218 | 22.44 | 19.97 | 36.08 | 3.69 | 24.93 | 303.4 | 1.09 | -0 | -0 | -0 | -0 |
| 306 | 17.55 | 19.61 | 35.43 | 3.59 | 25.73 | 227.6 | 1.64 | -0 | -0 | -0 | -0 |
| 388 | 11.85 | 19.28 | 34.83 | 3.13 | 26.50 | 153.7 | 2.75 | -0 | -0 | -0 | -0 |
| 594 | 6.47 | 19.10 | 34.51 | 3.46 | 27.12 | 95.1 | 3.21 | -0 | -0 | -0 | -0 |

INTERPOLATED AND COMPUTED VALUES AT STANDARD DEPTHS

| Z (m) | T (°C) | Cl (‰) | S (‰) | $\sigma_T$ (gm/L) | $\delta_T$ (cl/T) | $\delta$ (cl/T) | $\Delta D_{Z/0}$ (dyn m) | $\Delta D_{Z/Z\,MAX}$ (dyn m) | $Q_Z$ (m-dyn m) |
|---|---|---|---|---|---|---|---|---|---|
| 0 | 28.90 | 19.81 | 35.79 | 22.71 | 515.2 | 515.3 | 0 | 1.629 | 352.3 |
| 10 | 28.65 | 19.80 | 35.77 | 22.78 | 508.3 | 508.8 | .051 | 1.577 | 336.2 |
| 20 | 28.23 | 19.79 | 35.75 | 22.90 | 496.7 | 497.6 | .102 | 1.527 | 320.7 |
| 30 | 27.86 | 19.78 | 35.74 | 23.01 | 486.1 | 487.5 | .151 | 1.478 | 305.7 |
| 50 | 27.71 | 19.79 | 35.75 | 23.07 | 480.2 | 482.4 | .248 | 1.381 | 277.1 |
| 75 | 27.54 | 19.79 | 35.75 | 23.13 | 475.0 | 478.2 | .368 | 1.261 | 244.1 |
| 100 | 27.38 | 19.76 | 35.70 | 23.14 | 473.9 | 478.1 | .487 | 1.141 | 214.1 |
| 150 | 25.36 | 20.06 | 36.24 | 24.19 | 374.2 | 380.2 | .702 | .927 | 162.4 |
| 200 | 23.37 | 20.00 | 36.13 | 24.70 | 324.8 | 332.5 | .880 | .749 | 120.5 |
| 250 | 20.93 | 19.85 | 35.87 | 25.19 | 278.3 | 287.4 | 1.035 | .594 | 86.9 |
| 300 | 17.97 | 19.64 | 35.48 | 25.66 | 233.5 | 243.5 | 1.168 | .461 | 60.6 |
| 400 | 11.47 | 19.26 | 34.79 | 26.55 | 149.5 | 159.3 | 1.369 | .260 | 24.5 |
| 500 | 8.65 | 19.15 | 34.59 | 26.87 | 118.8 | 128.5 | 1.513 | .116 | 5.8 |
| 600 | 6.34 | 19.10 | 34.50 | 27.14 | 93.7 | 102.7 | 1.629 | 0 | 0 |

| STATION | DATE | TIME | LATITUDE | LONGITUDE | D |
|---|---|---|---|---|---|
| H 026 | OCT 18, 1963 | 1220-1300 | 15° 20.3'S | 166° 45.8'W | 43 |

OBSERVED AND COMPUTED VALUES AT OBSERVED DEPTHS

| Z (m) | T (°C) | Cl (‰) | S (‰) | $O_2$ (ml/L) | $\sigma_T$ (gm/L) | $\delta_T$ (cl/L) | AOU (ml/L) | $PO_4$ (μg at./L) | $NO_3$ (μg at./L) | $SiO_4$ (μg at./L) | $NO_2$ (μg at./L) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 0 | 27.80 | 19.96 | 36.06 | 4.47 | 23.28 | 461.0 | -.09 | .18 | .2 | .5 | .02 |
| 25 | 26.95 | 19.73 | 35.64 | 4.55 | 23.24 | 464.6 | -.09 | .05 | .2 | .6 | .01 |
| 50 | 26.60 | 19.83 | 35.82 | 4.56 | 23.49 | 441.0 | -.09 | .15 | .3 | 1.6 | .01 |
| 75 | 27.19 | 19.93 | 36.00 | 4.72 | 23.43 | 446.0 | -.29 | .18 | .1 | .7 | .06 |
| 99 | 26.20 | 19.68 | 35.55 | 4.59 | 23.41 | 448.4 | -.08 | .12 | .1 | .6 | 0 |
| 149 | 25.39 | 19.94 | 36.02 | 4.18 | 24.01 | 390.6 | .38 | .12 | 0 | .7 | .05 |
| 204 | 23.31 | 19.95 | 36.04 | 3.76 | 24.65 | 329.9 | .95 | .25 | 3.6 | .7 | .05 |
| 302 | 18.38 | 19.68 | 35.55 | 3.81 | 25.62 | 237.9 | 1.34 | .25 | 3.5 | 1.3 | .02 |
| 408 | 12.64 | 19.36 | 34.97 | 3.46 | 26.46 | 157.6 | 2.32 | .47 | 8.7 | 6.2 | .01 |
| 593 | 6.75 | 19.18 | 34.65 | 3.81 | 27.20 | 87.9 | 2.81 | 1.08 | 23.1 | 22.5 | 0 |

INTERPOLATED AND COMPUTED VALUES AT STANDARD DEPTHS

| Z (m) | T (°C) | Cl (‰) | S (‰) | $\sigma_T$ (gm/L) | $\delta_T$ (cl/T) | $\delta$ (cl/T) | $\Delta D_{Z/0}$ (dyn m) | $\Delta D_{Z/Z\,MAX}$ (dyn m) | $Q_Z$ (m-dynm) |
|---|---|---|---|---|---|---|---|---|---|
| 0 | 27.80 | 19.96 | 36.06 | 23.28 | 461.0 | 461.1 | 0 | 1.626 | 360.1 |
| 10 | 27.59 | 19.89 | 35.93 | 23.25 | 463.7 | 464.2 | .046 | 1.580 | 344.0 |
| 20 | 27.23 | 19.80 | 35.77 | 23.24 | 464.4 | 465.3 | .093 | 1.533 | 328.5 |
| 30 | 26.89 | 19.74 | 35.66 | 23.27 | 461.2 | 462.6 | .139 | 1.487 | 313.4 |
| 50 | 26.60 | 19.83 | 35.82 | 23.48 | 441.0 | 443.1 | .230 | 1.396 | 284.5 |
| 75 | 27.19 | 19.93 | 36.00 | 23.43 | 446.0 | 449.2 | .341 | 1.285 | 251.0 |
| 100 | 26.19 | 19.68 | 35.56 | 23.42 | 447.6 | 451.8 | .454 | 1.172 | 220.3 |
| 150 | 25.36 | 19.94 | 36.02 | 24.02 | 389.7 | 395.8 | .666 | .960 | 167.0 |
| 200 | 23.50 | 19.95 | 36.04 | 24.59 | 335.4 | 343.1 | .850 | .776 | 123.6 |
| 250 | 21.36 | 19.84 | 35.84 | 25.05 | 291.5 | 300.8 | 1.011 | .615 | 88.9 |
| 300 | 18.52 | 19.69 | 35.56 | 25.59 | 240.2 | 250.4 | 1.149 | .477 | 61.6 |
| 400 | 13.05 | 19.38 | 35.00 | 26.40 | 163.3 | 174.0 | 1.361 | .265 | 24.5 |
| 500 | 9.44 | 19.23 | 34.74 | 26.86 | 119.7 | 130.2 | 1.514 | .113 | 5.6 |
| 600 | 6.57 | 19.18 | 34.65 | 27.22 | 85.7 | 95.0 | 1.626 | 0 | 0 |

H 026

| STATION | DATE | TIME | LATITUDE | LONGITUDE | D |
|---|---|---|---|---|---|
| H 029 | OCT 19, 1963 | 1225-1300 | 15° 51.0'S | 162° 43.5'W | 36 |

OBSERVED AND COMPUTED VALUES AT OBSERVED DEPTHS

| Z (m) | T (°C) | Cl (‰) | S (‰) | $O_2$ (ml/L) | $\sigma_T$ (gm/L) | $\delta_T$ (cl/L) | AOU (ml/L) | $PO_4$ (μg at./L) | $NO_3$ (μg at./L) | $SiO_4$ (μg at./L) | $NO_2$ (μg at./L) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 0 | 27.60 | 19.97 | 36.08 | 4.54 | 23.36 | 453.5 | -.14 | .19 | .1 | .7 | .02 |
| 24 | 26.90 | 19.95 | 36.04 | 4.55 | 23.55 | 434.5 | -.10 | .15 | 0 | .5 | 0 |
| 49 | 26.52 | 19.96 | 36.06 | 4.61 | 23.69 | 421.7 | -.14 | .13 | .2 | .5 | 0 |
| 73 | 25.81 | 19.65 | 35.50 | 4.62 | 23.49 | 440.7 | -.08 | .10 | .2 | .6 | .02 |
| 97 | 25.61 | 19.65 | 35.50 | 4.63 | 23.55 | 434.8 | -.07 | .12 | .2 | .6 | 0 |
| 146 | 24.67 | 19.93 | 36.00 | 4.25 | 24.22 | 371.0 | .36 | .19 | .2 | .6 | .02 |
| 217 | 21.80 | 19.95 | 36.04 | 3.84 | 25.08 | 288.8 | .99 | .30 | 1.7 | .6 | .03 |
| 306 | 17.11 | 19.54 | 35.30 | 4.05 | 25.74 | 226.7 | 1.23 | .54 | 2.5 | 1.5 | .01 |
| 406 | 11.64 | 19.26 | 34.79 | 3.46 | 26.52 | 152.6 | 2.45 | 1.03 | 4.8 | 6.2 | 0 |
| 611 | 6.19 | 19.03 | 34.38 | 3.63 | 27.06 | 101.1 | 3.09 | 1.30 | 25.3 | 27.4 | 0 |

H 029

INTERPOLATED AND COMPUTED VALUES AT STANDARD DEPTHS

| Z (m) | T (°C) | Cl (‰) | S (‰) | $\sigma_T$ (gm/L) | $\delta_T$ (cl/T) | $\delta$ (cl/T) | $\Delta D_{Z/0}$ (dyn m) | $\Delta D_{Z/Z\,MAX}$ (dyn m) | $Q_Z$ (m-dynm) |
|---|---|---|---|---|---|---|---|---|---|
| 0 | 27.60 | 19.97 | 36.08 | 23.35 | 453.5 | 453.6 | 0 | 1.573 | 354.8 |
| 10 | 27.42 | 19.96 | 36.07 | 23.41 | 448.5 | 449.0 | .045 | 1.527 | 339.3 |
| 20 | 27.10 | 19.96 | 36.05 | 23.50 | 439.9 | 440.9 | .090 | 1.483 | 324.2 |
| 30 | 26.82 | 19.95 | 36.04 | 23.58 | 431.9 | 433.3 | .133 | 1.439 | 309.6 |
| 50 | 26.50 | 19.94 | 36.03 | 23.67 | 423.0 | 425.2 | .219 | 1.353 | 281.7 |
| 75 | 25.79 | 19.65 | 35.50 | 23.49 | 440.3 | 443.4 | .328 | 1.245 | 249.2 |
| 100 | 25.56 | 19.66 | 35.51 | 23.58 | 432.3 | 436.4 | .438 | 1.135 | 219.4 |
| 150 | 24.55 | 19.93 | 36.00 | 24.26 | 367.4 | 373.4 | .640 | .932 | 167.8 |
| 200 | 22.65 | 19.94 | 36.02 | 24.83 | 313.1 | 320.7 | .814 | .759 | 125.5 |
| 250 | 20.33 | 19.82 | 35.80 | 25.30 | 267.9 | 276.8 | .963 | .610 | 91.3 |
| 300 | 17.51 | 19.57 | 35.36 | 25.68 | 231.5 | 241.3 | 1.093 | .480 | 64.0 |
| 400 | 11.95 | 19.27 | 34.81 | 26.47 | 156.8 | 166.8 | 1.297 | .276 | 26.2 |
| 500 | 8.86 | 19.11 | 34.53 | 26.79 | 126.3 | 136.3 | 1.448 | .124 | 6.2 |
| 600 | 6.43 | 19.03 | 34.39 | 27.03 | 103.3 | 112.4 | 1.573 | 0 | 0 |

| STATION | DATE | TIME | LATITUDE | LONGITUDE | D |
|---|---|---|---|---|---|
| H 032 | OCT 20, 1963 | 1220-1300 | 16° 33.0'S | 158° 36.0'W | 37 |

OBSERVED AND COMPUTED VALUES AT OBSERVED DEPTHS

| Z | T | Cl | S | $O_2$ | $\sigma_T$ | $\delta_T$ | AOU | $PO_4$ | $NO_3$ | $SiO_4$ | $NO_2$ |
|---|---|---|---|---|---|---|---|---|---|---|---|
| (m) | (°C) | (‰) | (‰) | (ml/L) | (gm/L) | (cl/L) | (ml/L) | —— (µg at./L) —— | | | |
| 0 | 27.10 | 19.96 | 36.06 | 4.58 | 23.50 | 439.4 | -.15 | .20 | .2 | 1.2 | -0 |
| 25 | 26.11 | 19.93 | 36.00 | 4.68 | 23.78 | 413.3 | -.18 | .13 | .2 | .2 | 0 |
| 49 | 25.72 | 19.96 | 36.06 | 4.68 | 23.94 | 397.8 | -.15 | .17 | .1 | .4 | 0 |
| 73 | 25.34 | 19.95 | 36.04 | 4.86 | 24.04 | 387.9 | -.30 | .14 | .2 | .5 | .02 |
| 98 | 25.08 | 19.97 | 36.08 | 4.68 | 24.15 | 377.7 | -.10 | .14 | .1 | .5 | 0 |
| 147 | 24.07 | 19.97 | 36.08 | 4.30 | 24.45 | 348.6 | .35 | .20 | .3 | .4 | .07 |
| 228 | 21.10 | 19.84 | 35.84 | 4.08 | 25.13 | 284.7 | .81 | .39 | 1.5 | .5 | .02 |
| 322 | 16.18 | 19.53 | 35.28 | 4.03 | 25.94 | 207.2 | 1.34 | .59 | 4.3 | 3.3 | .02 |
| 365 | 11.17 | 19.21 | 34.70 | 3.66 | 26.53 | 150.9 | 2.32 | 1.07 | 5.5 | 11.3 | 0 |
| 616 | 6.32 | 19.21 | 34.70 | 3.52 | 27.30 | 78.4 | 3.16 | 1.91 | 15.2 | 32.5 | 0 |

INTERPOLATED AND COMPUTED VALUES AT STANDARD DEPTHS

| Z | T | Cl | S | $\sigma_T$ | $\delta_T$ | $\delta$ | $\Delta D_{Z/0}$ | $\Delta D_{Z/Z\,MAX}$ | $Q_Z$ |
|---|---|---|---|---|---|---|---|---|---|
| (m) | (°C) | (‰) | (‰) | (gm/L) | (cl/T) | (cl/T) | (dyn m) | (dyn m) | (m-dynm) |
| 0 | 27.10 | 19.96 | 36.06 | 23.50 | 439.4 | 439.5 | 0 | 1.462 | 325.0 |
| 10 | 26.85 | 19.95 | 36.04 | 23.57 | 432.8 | 433.4 | .044 | 1.418 | 310.6 |
| 20 | 26.44 | 19.94 | 36.02 | 23.68 | 422.0 | 422.9 | .086 | 1.375 | 296.6 |
| 30 | 26.04 | 19.93 | 36.01 | 23.80 | 410.5 | 411.8 | .128 | 1.334 | 283.1 |
| 50 | 25.71 | 19.96 | 36.06 | 23.94 | 397.4 | 399.5 | .209 | 1.253 | 257.2 |
| 75 | 25.32 | 19.95 | 36.04 | 24.05 | 387.1 | 390.2 | .308 | 1.154 | 227.1 |
| 100 | 25.05 | 19.97 | 36.08 | 24.16 | 376.7 | 380.7 | .404 | 1.057 | 199.5 |
| 150 | 23.99 | 19.97 | 36.07 | 24.47 | 346.7 | 352.6 | .588 | .874 | 151.2 |
| 200 | 22.33 | 19.89 | 35.94 | 24.86 | 310.3 | 317.8 | .755 | .707 | 111.7 |
| 250 | 20.16 | 19.78 | 35.72 | 25.29 | 269.0 | 278.0 | .904 | .558 | 80.1 |
| 300 | 17.57 | 19.61 | 35.43 | 25.72 | 228.0 | 237.9 | 1.033 | .429 | 55.4 |
| 400 | 10.32 | 19.20 | 34.68 | 26.67 | 138.3 | 147.3 | 1.226 | .236 | 22.2 |
| 500 | 8.25 | 19.19 | 34.67 | 26.99 | 107.3 | 116.7 | 1.358 | .104 | 5.2 |
| 600 | 6.56 | 19.21 | 34.70 | 27.26 | 82.0 | 91.3 | 1.462 | 0 | 0 |

| STATION | DATE | TIME | LATITUDE | LONGITUDE | D |
|---|---|---|---|---|---|
| H 035 | OCT 21, 1963 | 1220-1310 | 17° 07.0'S | 154° 17.0'W | 35 |

OBSERVED AND COMPUTED VALUES AT OBSERVED DEPTHS

| Z | T | Cl | S | $O_2$ | $\sigma_T$ | $\delta_T$ | AOU | $PO_4$ | $NO_3$ | $SiO_4$ | $NO_2$ |
|---|---|---|---|---|---|---|---|---|---|---|---|
| (m) | (°C) | (‰) | (‰) | (ml/L) | (gm/L) | (cl/L) | (ml/L) | —— (µg at /L) —— | | | |
| 0 | 27.00 | 20.08 | 36.27 | 4.55 | 23.70 | 420.7 | -.12 | .23 | .2 | .8 | 0 |
| 25 | 26.93 | 20.05 | 36.22 | 4.62 | 23.68 | 422.5 | -.18 | .18 | .1 | .8 | .01 |
| 49 | 26.31 | 20.05 | 36.22 | 4.63 | 23.88 | 403.7 | -.15 | .17 | .1 | .7 | 0 |
| 74 | 25.92 | 20.00 | 36.13 | 4.66 | 23.93 | 398.5 | -.15 | .16 | .1 | .7 | .02 |
| 99 | 25.64 | 19.99 | 36.11 | 4.67 | 24.00 | 391.5 | -.14 | .15 | 0 | .8 | 0 |
| 148 | 24.67 | 19.97 | 36.08 | 4.45 | 24.27 | 365.8 | .16 | .17 | 0 | .9 | 0 |
| 202 | 21.90 | 19.92 | 35.99 | 4.04 | 25.01 | 295.4 | .78 | .30 | 1.6 | .8 | .02 |
| 305 | 17.97 | 19.61 | 35.43 | 4.18 | 25.62 | 237.4 | 1.01 | .43 | 3.0 | 1.5 | .01 |
| 378 | 13.67 | 19.36 | 34.97 | 3.99 | 26.25 | 177.4 | 1.67 | .73 | 8.2 | 4.6 | 0 |
| 594 | 6.80 | 19.06 | 34.43 | 3.74 | 27.02 | 104.7 | 2.88 | 1.88 | 21.5 | 24.8 | 0 |

INTERPOLATED AND COMPUTED VALUES AT STANDARD DEPTHS

| Z | T | Cl | S | $\sigma_T$ | $\delta_T$ | $\delta$ | $\Delta D_{Z/0}$ | $\Delta D_{Z/Z\,MAX}$ | $Q_Z$ |
|---|---|---|---|---|---|---|---|---|---|
| (m) | (°C) | (‰) | (‰) | (gm/L) | (cl/T) | (cl/T) | (dyn m) | (dyn m) | (m-dynm) |
| 0 | 27.00 | 20.08 | 36.27 | 23.70 | 420.7 | 420.8 | 0 | 1.552 | 360.9 |
| 10 | 26.98 | 20.07 | 36.25 | 23.68 | 422.0 | 422.5 | .042 | 1.510 | 345.6 |
| 20 | 26.95 | 20.06 | 36.23 | 23.68 | 422.4 | 423.3 | .084 | 1.468 | 330.7 |
| 30 | 26.85 | 20.05 | 36.23 | 23.71 | 419.7 | 421.0 | .127 | 1.426 | 316.2 |
| 50 | 26.30 | 20.05 | 36.22 | 23.88 | 403.5 | 405.6 | .209 | 1.343 | 288.5 |
| 75 | 25.91 | 20.00 | 36.13 | 23.93 | 398.2 | 401.4 | .310 | 1.242 | 256.2 |
| 100 | 25.62 | 19.99 | 36.11 | 24.01 | 391.1 | 395.2 | .410 | 1.143 | 226.4 |
| 150 | 24.59 | 19.97 | 36.07 | 24.29 | 363.8 | 369.8 | .601 | .951 | 174.1 |
| 200 | 22.04 | 19.92 | 35.99 | 24.98 | 298.9 | 306.4 | .770 | .782 | 130.7 |
| 250 | 20.31 | 19.79 | 35.75 | 25.27 | 270.7 | 279.6 | .917 | .636 | 95.3 |
| 300 | 18.21 | 19.63 | 35.46 | 25.59 | 240.6 | 250.7 | 1.049 | .503 | 66.8 |
| 400 | 12.81 | 19.30 | 34.87 | 26.35 | 168.3 | 178.9 | 1.264 | .288 | 27.2 |
| 500 | 9.42 | 19.13 | 34.56 | 26.73 | 132.4 | 142.8 | 1.425 | .128 | 6.4 |
| 600 | 6.65 | 19.06 | 34.43 | 27.04 | 103.1 | 112.4 | 1.552 | 0 | 0 |

| STATION | DATE | TIME | LATITUDE | LONGITUDE | D |
|---|---|---|---|---|---|
| H 038 | OCT 22, 1963 | 1220-1305 | 17° 20.3'S | 150° 04.0'W | 39 |

OBSERVED AND COMPUTED VALUES AT OBSERVED DEPTHS

| Z (m) | T (°C) | Cl (‰) | S (‰) | $O_2$ (ml/L) | $\sigma_T$ (gm/L) | $\delta_T$ (cl/L) | AOU (ml/L) | $PO_4$ | $NO_3$ | $SiO_4$ | $NO_2$ |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | (μg at./L) | | | |
| 0 | 27.45 | 20.14 | 36.38 | 4.53 | 23.63 | 426.8 | -.13 | .14 | .2 | .7 | .03 |
| 25 | 26.53 | 20.09 | 36.29 | 4.58 | 23.86 | 405.1 | -.11 | .12 | 0 | .6 | 0 |
| 50 | 26.22 | 20.09 | 36.29 | 4.64 | 23.96 | 395.8 | -.15 | .12 | 0 | .7 | .01 |
| 75 | 25.80 | 20.05 | 36.22 | 4.68 | 24.04 | 388.4 | -.16 | .10 | 0 | .5 | .02 |
| 100 | 25.35 | 20.00 | 36.13 | 4.66 | 24.11 | 381.7 | -.10 | .10 | 0 | .5 | .01 |
| 150 | 24.69 | 20.02 | 36.17 | 4.54 | 24.34 | 359.8 | .06 | .10 | 0 | .6 | .02 |
| 314 | 16.73 | 19.54 | 35.30 | 4.10 | 25.83 | 218.1 | 1.22 | .44 | 7.1 | 2.1 | .02 |
| 410 | 11.54 | 19.23 | 34.74 | 3.76 | 26.49 | 154.8 | 2.17 | 1.00 | 17.7 | 7.9 | .01 |
| 501 | 6.34 | 19.09 | 34.49 | 3.73 | 26.84 | 121.8 | 2.65 | -0 | -0 | -0 | -0 |
| 704 | 5.80 | 19.08 | 34.47 | 3.44 | 27.18 | 89.6 | 3.34 | 2.05 | 31.6 | 35.3 | 0 |

INTERPOLATED AND COMPUTED VALUES AT STANDARD DEPTHS

| Z (m) | T (°C) | Cl (‰) | S (‰) | $\sigma_T$ (gm/L) | $\delta_T$ (cl/T) | $\delta$ (cl/T) | $\Delta D_{Z/0}$ (dyn m) | $\Delta D_{Z/Z\,MAX}$ (dyn m) | $Q_Z$ (m-dynm) |
|---|---|---|---|---|---|---|---|---|---|
| 0 | 27.45 | 20.14 | 36.38 | 23.63 | 426.8 | 426.9 | 0 | 1.648 | 425.2 |
| 10 | 27.22 | 20.13 | 36.36 | 23.69 | 421.4 | 421.9 | .042 | 1.606 | 408.9 |
| 20 | 26.84 | 20.11 | 36.32 | 23.78 | 412.3 | 413.3 | .084 | 1.564 | 393.1 |
| 30 | 26.47 | 20.09 | 36.29 | 23.88 | 403.5 | 404.8 | .125 | 1.523 | 377.7 |
| 50 | 26.22 | 20.09 | 36.29 | 23.96 | 395.8 | 397.9 | .205 | 1.443 | 348.0 |
| 75 | 25.80 | 20.05 | 36.22 | 24.04 | 388.4 | 391.6 | .304 | 1.344 | 313.2 |
| 100 | 25.35 | 20.00 | 36.13 | 24.11 | 381.7 | 385.7 | .401 | 1.247 | 280.8 |
| 150 | 24.69 | 20.02 | 36.17 | 24.34 | 359.8 | 365.8 | .589 | 1.059 | 223.1 |
| 200 | 22.97 | 19.89 | 35.93 | 24.67 | 328.0 | 335.7 | .764 | .884 | 174.5 |
| 250 | 20.75 | 19.75 | 35.67 | 25.09 | 287.9 | 296.9 | .923 | .726 | 134.3 |
| 300 | 17.76 | 19.59 | 35.38 | 25.64 | 235.7 | 245.6 | 1.058 | .590 | 101.4 |
| 400 | 12.05 | 19.25 | 34.78 | 26.43 | 161.0 | 171.2 | 1.267 | .382 | 52.8 |
| 500 | 8.37 | 19.09 | 34.49 | 26.84 | 122.1 | 131.6 | 1.418 | .230 | 22.2 |
| 600 | 6.99 | 19.08 | 34.47 | 27.02 | 104.7 | 114.5 | 1.541 | .107 | 5.4 |
| 700 | 5.84 | 19.08 | 34.47 | 27.17 | 90.1 | 99.8 | 1.648 | 0 | 0 |

H 038

| STATION | DATE | TIME | LATITUDE | LONGITUDE | D |
|---|---|---|---|---|---|
| H 041 | OCT 29, 1963 | 1200-1300 | 19° 40.2'S | 146° 04.1'W | 35 |

OBSERVED AND COMPUTED VALUES AT OBSERVED DEPTHS

| Z (m) | T (°C) | Cl (‰) | S (‰) | $O_2$ (ml/L) | $\sigma_T$ (gm/L) | $\delta_T$ (cl/L) | AOU (ml/L) | $PO_4$ | $NO_3$ | $SiO_4$ | $NO_2$ |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | (μg at./L) | | | |
| 0 | 25.40 | 20.07 | 36.26 | 4.67 | 24.19 | 374.0 | -.12 | .16 | 0 | .5 | .02 |
| 23 | 25.63 | 20.06 | 36.24 | 4.65 | 24.10 | 382.1 | -.12 | .14 | 0 | .5 | 0 |
| 46 | 25.40 | 20.09 | 36.29 | 4.62 | 24.22 | 371.4 | -.07 | .12 | 0 | .5 | .01 |
| 69 | 24.64 | 20.03 | 36.18 | 4.68 | 24.37 | 357.1 | -.07 | .10 | .1 | .5 | .04 |
| 92 | 24.36 | 20.01 | 36.15 | 4.70 | 24.42 | 351.7 | -.07 | .10 | 0 | .5 | .01 |
| 139 | 22.44 | 19.89 | 35.93 | 4.35 | 24.82 | 313.8 | .43 | .23 | .6 | .5 | .05 |
| 246 | 18.17 | 19.65 | 35.50 | 4.24 | 25.63 | 236.8 | .93 | .40 | 4.0 | .9 | .02 |
| 354 | 14.88 | 19.45 | 35.14 | 4.18 | 26.12 | 190.0 | 1.34 | .44 | 4.2 | 1.1 | .01 |
| 449 | 10.72 | 19.26 | 34.79 | 4.18 | 26.68 | 136.6 | 1.85 | 1.05 | 16.8 | 5.8 | .02 |
| 636 | 6.16 | 19.04 | 34.40 | 3.94 | 27.08 | 99.3 | 2.79 | 1.92 | 30.1 | 19.6 | 0 |

INTERPOLATED AND COMPUTED VALUES AT STANDARD DEPTHS

| Z (m) | T (°C) | Cl (‰) | S (‰) | $\sigma_T$ (gm/L) | $\delta_T$ (cl/T) | $\delta$ (cl/T) | $\Delta D_{Z/0}$ (dyn m) | $\Delta D_{Z/Z\,MAX}$ (dyn m) | $Q_Z$ (m-dynm) |
|---|---|---|---|---|---|---|---|---|---|
| 0 | 25.40 | 20.07 | 36.26 | 24.19 | 374.0 | 374.1 | 0 | 1.413 | 335.4 |
| 10 | 25.57 | 20.06 | 36.24 | 24.12 | 380.1 | 380.6 | .038 | 1.375 | 321.5 |
| 20 | 25.62 | 20.06 | 36.24 | 24.11 | 381.8 | 382.7 | .076 | 1.337 | 307.9 |
| 30 | 25.58 | 20.07 | 36.25 | 24.13 | 379.7 | 381.0 | .114 | 1.299 | 294.7 |
| 50 | 25.31 | 20.08 | 36.28 | 24.23 | 369.4 | 371.5 | .189 | 1.224 | 269.5 |
| 75 | 24.57 | 20.03 | 36.18 | 24.38 | 355.8 | 358.8 | .281 | 1.133 | 240.1 |
| 100 | 24.12 | 19.99 | 36.12 | 24.47 | 346.7 | 350.7 | .369 | 1.044 | 212.9 |
| 150 | 22.12 | 19.87 | 35.89 | 24.88 | 307.8 | 313.5 | .535 | .878 | 164.8 |
| 200 | 20.36 | 19.76 | 35.70 | 25.22 | 275.6 | 282.8 | .684 | .729 | 124.7 |
| 250 | 18.07 | 19.64 | 35.49 | 25.64 | 235.3 | 243.7 | .816 | .597 | 91.5 |
| 300 | 16.66 | 19.55 | 35.32 | 25.86 | 214.9 | 224.4 | .933 | .480 | 64.6 |
| 400 | 12.87 | 19.34 | 34.94 | 26.39 | 164.2 | 174.8 | 1.133 | .280 | 26.6 |
| 500 | 9.31 | 19.17 | 34.64 | 26.80 | 125.1 | 135.4 | 1.288 | .125 | 6.3 |
| 600 | 6.92 | 19.07 | 34.44 | 27.01 | 105.6 | 115.2 | 1.413 | 0 | 0 |

H 041

| STATION | DATE | TIME | LATITUDE | LONGITUDE | D |
|---|---|---|---|---|---|
| H 044 | OCT 30, 1963 | 1200- | 21° 43.8'S | 142° 46.2'W | 37 |

OBSERVED AND COMPUTED VALUES AT OBSERVED DEPTHS

| Z (m) | T (°C) | Cl (‰) | S (‰) | $O_2$ (ml/L) | $\sigma_T$ (gm/L) | $\delta_T$ (cl/L) | AOU (ml/L) | $PO_4$ | $NO_3$ | $SiO_4$ | $NO_2$ |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | —— ($\mu$g at./L) | | | —— |
| 0 | 23.70 | 19.83 | 35.82 | 4.79 | 24.37 | 356.4 | -.10 | .15 | 0 | .6 | .01 |
| 24 | 23.80 | 19.82 | 35.81 | 4.79 | 24.33 | 360.5 | -.11 | .14 | 0 | .5 | 0 |
| 48 | 22.91 | 19.81 | 35.79 | 4.85 | 24.58 | 337.1 | -.10 | .10 | 0 | .6 | 0 |
| 72 | 22.65 | 19.81 | 35.79 | 4.84 | 24.65 | 330.0 | -.07 | .10 | .1 | .6 | .01 |
| 96 | 21.86 | 19.73 | 35.64 | 4.88 | 24.76 | 319.1 | -.04 | .10 | 0 | .6 | 0 |
| 144 | 20.36 | 19.71 | 35.61 | 4.44 | 25.15 | 282.7 | .53 | .16 | 1.0 | .6 | .06 |
| 230 | 18.48 | 19.64 | 35.48 | 4.34 | 25.54 | 245.5 | .80 | .25 | 2.9 | .6 | .01 |
| 315 | 15.09 | 19.51 | 35.25 | 4.41 | 26.16 | 186.5 | 1.08 | .51 | 6.7 | 1.8 | .01 |
| 394 | 11.86 | 19.32 | 34.90 | 4.25 | 26.56 | 148.5 | 1.63 | .85 | 13.4 | 4.4 | .01 |
| 583 | 7.19 | 19.07 | 34.45 | 4.87 | 26.98 | 108.5 | 1.69 | .76 | 23.6 | 5.0 | 0 |

H 0

INTERPOLATED AND COMPUTED VALUES AT STANDARD DEPTHS

| Z (m) | T (°C) | Cl (‰) | S (‰) | $\sigma_T$ (gm/L) | $\delta_T$ (cl/T) | $\delta$ (cl/T) | $\Delta D_{Z/0}$ (dyn m) | $\Delta D_{Z/Z\,MAX}$ (dyn m) | $Q_Z$ (m-dynm) |
|---|---|---|---|---|---|---|---|---|---|
| 0 | 23.70 | 19.83 | 35.82 | 24.37 | 356.4 | 356.5 | 0 | 1.325 | 317.3 |
| 10 | 23.77 | 19.82 | 35.81 | 24.34 | 359.5 | 360.0 | .036 | 1.289 | 304.2 |
| 20 | 23.79 | 19.82 | 35.81 | 24.33 | 360.3 | 361.2 | .072 | 1.253 | 291.5 |
| 30 | 23.64 | 19.82 | 35.80 | 24.37 | 356.2 | 357.5 | .108 | 1.217 | 279.2 |
| 50 | 22.89 | 19.81 | 35.79 | 24.58 | 336.5 | 338.5 | .177 | 1.147 | 255.5 |
| 75 | 22.57 | 19.80 | 35.77 | 24.66 | 328.7 | 331.7 | .261 | 1.063 | 227.9 |
| 100 | 21.76 | 19.73 | 35.64 | 24.79 | 316.6 | 320.5 | .343 | .982 | 202.3 |
| 150 | 20.25 | 19.71 | 35.60 | 25.17 | 280.5 | 285.9 | .494 | .830 | 157.0 |
| 200 | 19.21 | 19.67 | 35.53 | 25.39 | 259.8 | 266.8 | .632 | .692 | 119.0 |
| 250 | 17.80 | 19.61 | 35.43 | 25.66 | 233.4 | 241.7 | .760 | .565 | 87.6 |
| 300 | 15.80 | 19.53 | 35.29 | 26.03 | 198.4 | 207.7 | .872 | .453 | 62.1 |
| 400 | 11.68 | 19.31 | 34.88 | 26.57 | 147.0 | 156.9 | 1.054 | .270 | 26.0 |
| 500 | 9.02 | 19.15 | 34.59 | 26.81 | 124.2 | 134.3 | 1.200 | .125 | 6.2 |
| 600 | 6.85 | 19.06 | 34.43 | 27.01 | 105.5 | 115.1 | 1.325 | 0 | 0 |

| STATION | DATE | TIME | LATITUDE | LONGITUDE | D |
|---|---|---|---|---|---|
| H 047 | OCT 31, 1963 | 1200-1300 | 23° 53.8'S | 139° 09.4'W | 35 |

OBSERVED AND COMPUTED VALUES AT OBSERVED DEPTHS

| Z (m) | T (°C) | Cl (‰) | S (‰) | $O_2$ (ml/L) | $\sigma_T$ (gm/L) | $\delta_T$ (cl/L) | AOU (ml/L) | $PO_4$ | $NO_3$ | $SiO_4$ | $NO_2$ |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | —— ($\mu$g at./L) | | | —— |
| 0 | 23.35 | 19.83 | 35.82 | 4.84 | 24.48 | 346.6 | -.13 | .15 | 0 | .5 | 0 |
| 24 | 23.42 | 19.84 | 35.84 | 4.83 | 24.47 | 347.3 | -.12 | .10 | 0 | .5 | 0 |
| 48 | 23.11 | 19.83 | 35.82 | 4.86 | 24.55 | 340.0 | -.13 | .10 | 0 | .5 | 0 |
| 72 | 22.22 | 19.78 | 35.73 | 4.91 | 24.73 | 322.2 | -.10 | .09 | 0 | .5 | 0 |
| 96 | 21.58 | 19.74 | 35.66 | 4.97 | 24.86 | 310.4 | -.11 | .10 | 0 | .5 | 0 |
| 144 | 20.60 | 19.70 | 35.59 | 5.02 | 25.07 | 290.1 | -.07 | -0 | -0 | .2 | -0 |
| 208 | 19.23 | 19.68 | 35.55 | 4.65 | 25.40 | 258.4 | .42 | .14 | .6 | .6 | .09 |
| 294 | 16.11 | 19.56 | 35.34 | 4.49 | 26.00 | 201.7 | .89 | .33 | 4.5 | 1.5 | .01 |
| 380 | 12.75 | 19.39 | 35.03 | 4.39 | 26.48 | 155.7 | 1.38 | .64 | 9.7 | 2.6 | .02 |
| 565 | 7.48 | 19.10 | 34.51 | 4.59 | 26.98 | 108.3 | 1.92 | 1.30 | 25.1 | 7.8 | 0 |

H 0

INTERPOLATED AND COMPUTED VALUES AT STANDARD DEPTHS

| Z (m) | T (°C) | Cl (‰) | S (‰) | $\sigma_T$ (gm/L) | $\delta_T$ (cl/T) | $\delta$ (cl/T) | $\Delta D_{Z/0}$ (dyn m) | $\Delta D_{Z/Z\,MAX}$ (dyn m) | $Q_Z$ (m-dynm) |
|---|---|---|---|---|---|---|---|---|---|
| 0 | 23.35 | 19.83 | 35.82 | 24.47 | 346.6 | 346.7 | 0 | 1.321 | 317.0 |
| 10 | 23.40 | 19.84 | 35.84 | 24.47 | 347.1 | 347.6 | .035 | 1.286 | 304.0 |
| 20 | 23.42 | 19.84 | 35.84 | 24.47 | 347.2 | 348.1 | .070 | 1.251 | 291.3 |
| 30 | 23.36 | 19.84 | 35.84 | 24.48 | 345.9 | 347.2 | .104 | 1.216 | 279.0 |
| 50 | 23.06 | 19.83 | 35.82 | 24.56 | 338.9 | 340.9 | .173 | 1.148 | 255.3 |
| 75 | 22.15 | 19.78 | 35.72 | 24.74 | 320.9 | 323.8 | .256 | 1.064 | 227.7 |
| 100 | 21.51 | 19.74 | 35.65 | 24.87 | 309.0 | 312.7 | .336 | .985 | 202.1 |
| 150 | 20.49 | 19.70 | 35.58 | 25.09 | 287.6 | 293.1 | .487 | .833 | 156.6 |
| 200 | 19.43 | 19.68 | 35.56 | 25.35 | 263.1 | 270.1 | .628 | .693 | 118.5 |
| 250 | 17.89 | 19.62 | 35.45 | 25.66 | 233.7 | 242.0 | .756 | .565 | 87.0 |
| 300 | 15.89 | 19.55 | 35.31 | 26.03 | 198.7 | 208.0 | .869 | .452 | 61.6 |
| 400 | 12.07 | 19.34 | 34.94 | 26.55 | 149.5 | 159.7 | 1.052 | .268 | 25.6 |
| 500 | 9.10 | 19.17 | 34.63 | 26.83 | 122.9 | 133.1 | 1.199 | .122 | 6.1 |
| 600 | 6.68 | 19.07 | 34.46 | 27.06 | 101.2 | 110.5 | 1.321 | 0 | 0 |

| STATION | DATE | TIME | LATITUDE | LONGITUDE | D |
|---|---|---|---|---|---|
| H 049 | NOV 1, 1963 | 0600-0650 | 24° 55.7'S | 137° 03.2'W | 35 |

OBSERVED AND COMPUTED VALUES AT OBSERVED DEPTHS

| Z | T | Cl | S | $O_2$ | $\sigma_T$ | $\delta_T$ | AOU | $PO_4$ | $NO_3$ | $SiO_4$ | $NO_2$ |
|---|---|---|---|---|---|---|---|---|---|---|---|
| (m) | (°C) | (‰) | (‰) | (ml/L) | (gm/L) | (cl/L) | (ml/L) | ——— | ($\mu$g at./L) | | ——— |
| 0 | 21.60 | 19.67 | 35.53 | 5.06 | 24.75 | 320.0 | -.20 | .14 | .2 | .8 | .03 |
| 24 | 21.74 | 19.64 | 35.48 | 4.97 | 24.67 | 327.7 | -.12 | .14 | .3 | .7 | .02 |
| 48 | 20.74 | 19.66 | 35.52 | 5.08 | 24.98 | 298.9 | -.14 | .15 | .1 | .7 | .06 |
| 72 | 20.28 | 19.66 | 35.52 | 5.05 | 25.10 | 287.2 | -.07 | .13 | .2 | .7 | .05 |
| 96 | 19.89 | 19.68 | 35.55 | 4.94 | 25.23 | 274.8 | .07 | .15 | .3 | .7 | .03 |
| 144 | 18.88 | 19.64 | 35.48 | 4.75 | 25.44 | 255.1 | .35 | .15 | .6 | .8 | .08 |
| 229 | 16.73 | 19.54 | 35.30 | 4.63 | 25.83 | 218.1 | .69 | .24 | 3.3 | 1.2 | .05 |
| 311 | 13.92 | 19.41 | 35.07 | 4.50 | 26.27 | 175.7 | 1.13 | .44 | -0 | -0 | -0 |
| 407 | 10.55 | 19.21 | 34.70 | 4.47 | 26.64 | 140.4 | 1.59 | .66 | 16.6 | 4.5 | -0 |
| 608 | 6.58 | 19.01 | 34.34 | 4.69 | 26.98 | 108.6 | 1.97 | 1.23 | 28.6 | 12.0 | .03 |

INTERPOLATED AND COMPUTED VALUES AT STANDARD DEPTHS

H 049

| Z | T | Cl | S | $\sigma_T$ | $\delta_T$ | $\delta$ | $\Delta D_{Z/0}$ | $\Delta D_{Z/Z\,MAX}$ | $Q_Z$ |
|---|---|---|---|---|---|---|---|---|---|
| (m) | (°C) | (‰) | (‰) | (gm/L) | (cl/T) | (cl/T) | (dyn m) | (dyn m) | (m-dynm) |
| 0 | 21.60 | 19.67 | 35.53 | 24.75 | 320.0 | 320.2 | 0 | 1.213 | 299.4 |
| 10 | 21.70 | 19.65 | 35.49 | 24.69 | 325.7 | 326.2 | .032 | 1.181 | 287.5 |
| 20 | 21.73 | 19.64 | 35.48 | 24.68 | 327.2 | 328.1 | .065 | 1.148 | 275.8 |
| 30 | 21.49 | 19.64 | 35.49 | 24.75 | 320.6 | 321.8 | .098 | 1.116 | 264.5 |
| 50 | 20.69 | 19.66 | 35.52 | 24.99 | 297.8 | 299.7 | .160 | 1.054 | 242.8 |
| 75 | 20.22 | 19.66 | 35.52 | 25.12 | 285.4 | 288.2 | .233 | .980 | 217.4 |
| 100 | 19.79 | 19.68 | 35.54 | 25.25 | 272.8 | 276.4 | .304 | .909 | 193.8 |
| 150 | 18.69 | 19.63 | 35.46 | 25.47 | 251.9 | 257.1 | .437 | .776 | 151.6 |
| 200 | 17.36 | 19.57 | 35.35 | 25.71 | 228.9 | 235.5 | .560 | .653 | 115.9 |
| 250 | 15.92 | 19.50 | 35.22 | 25.95 | 206.0 | 213.7 | .673 | .541 | 86.1 |
| 300 | 14.25 | 19.42 | 35.09 | 26.22 | 180.7 | 189.3 | .773 | .440 | 61.6 |
| 400 | 10.77 | 19.22 | 34.72 | 26.62 | 142.6 | 152.0 | .944 | .269 | 26.1 |
| 500 | 8.51 | 19.09 | 34.49 | 26.82 | 124.1 | 133.7 | 1.087 | .126 | 6.3 |
| 600 | 6.71 | 19.01 | 34.35 | 26.97 | 109.7 | 119.1 | 1.213 | 0 | 0 |

| STATION | DATE | TIME | LATITUDE | LONGITUDE | D |
|---|---|---|---|---|---|
| H 052 | NOV 2, 1963 | 1200-1250 | 26° 59.1'S | 133° 55.8'W | 29 |

OBSERVED AND COMPUTED VALUES AT OBSERVED DEPTHS

| Z | T | Cl | S | $O_2$ | $\sigma_T$ | $\delta_T$ | AOU | $PO_4$ | $NO_3$ | $SiO_4$ | $NO_2$ |
|---|---|---|---|---|---|---|---|---|---|---|---|
| (m) | (°C) | (‰) | (‰) | (ml/L) | (gm/L) | (cl/L) | (ml/L) | ——— | ($\mu$g at./L) | | ——— |
| 0 | 20.72 | 19.67 | 35.53 | 5.08 | 25.00 | 297.1 | -.14 | .12 | .6 | .7 | .09 |
| 21 | 20.74 | 19.67 | 35.53 | 5.03 | 24.99 | 297.6 | -.09 | .11 | .4 | .8 | .09 |
| 42 | 20.54 | 19.66 | 35.52 | 5.08 | 25.03 | 293.8 | -.13 | .13 | .2 | .7 | .05 |
| 64 | 19.68 | 19.64 | 35.48 | 5.16 | 25.23 | 274.7 | -.13 | .13 | .3 | .7 | .03 |
| 85 | 19.21 | 19.64 | 35.48 | 5.07 | 25.35 | 263.1 | .00 | .16 | .3 | .7 | .03 |
| 127 | 18.26 | 19.58 | 35.37 | 5.17 | 25.51 | 248.1 | -.01 | .18 | .3 | .8 | .05 |
| 200 | 16.06 | 19.50 | 35.23 | 4.77 | 25.93 | 208.6 | .62 | .29 | 3.5 | 1.2 | .02 |
| 288 | 13.89 | 19.49 | 35.21 | 4.52 | 26.39 | 164.5 | 1.10 | .48 | 8.2 | 2.1 | .09 |
| 345 | 12.09 | 19.26 | 34.79 | 4.48 | 26.43 | 160.7 | 1.38 | .62 | 14.2 | 3.6 | .08 |
| 496 | 8.05 | 19.09 | 34.49 | 4.66 | 26.88 | 117.6 | 1.76 | -0 | -0 | -0 | -0 |

H 052

INTERPOLATED AND COMPUTED VALUES AT STANDARD DEPTHS

| Z | T | Cl | S | $\sigma_T$ | $\delta_T$ | $\delta$ | $\Delta D_{Z/0}$ | $\Delta D_{Z/Z\,MAX}$ | $Q_Z$ |
|---|---|---|---|---|---|---|---|---|---|
| (m) | (°C) | (‰) | (‰) | (gm/L) | (cl/T) | (cl/T) | (dyn m) | (dyn m) | (m-dynm) |
| 0 | 20.72 | 19.67 | 35.53 | 24.99 | 297.1 | 297.2 | 0 | 1.013 | 215.1 |
| 10 | 20.74 | 19.67 | 35.53 | 24.99 | 297.5 | 298.0 | .030 | .983 | 205.1 |
| 20 | 20.74 | 19.67 | 35.53 | 24.99 | 297.6 | 298.5 | .060 | .953 | 195.4 |
| 30 | 20.67 | 19.67 | 35.53 | 25.00 | 296.4 | 297.6 | .089 | .923 | 186.0 |
| 50 | 20.26 | 19.65 | 35.50 | 25.09 | 287.6 | 289.5 | .148 | .865 | 168.2 |
| 75 | 19.42 | 19.64 | 35.48 | 25.30 | 268.3 | 271.0 | .218 | .794 | 147.4 |
| 100 | 18.83 | 19.61 | 35.43 | 25.41 | 257.1 | 260.6 | .285 | .728 | 128.4 |
| 150 | 17.45 | 19.55 | 35.31 | 25.66 | 233.6 | 238.6 | .409 | .603 | 95.1 |
| 200 | 16.06 | 19.50 | 35.23 | 25.93 | 208.6 | 214.8 | .523 | .490 | 67.8 |
| 250 | 14.73 | 19.49 | 35.21 | 26.21 | 181.6 | 189.0 | .624 | .389 | 45.8 |
| 300 | 13.48 | 19.44 | 35.11 | 26.40 | 163.7 | 172.0 | .714 | .299 | 28.6 |
| 400 | 10.35 | 19.17 | 34.63 | 26.63 | 142.1 | 151.1 | .876 | .137 | 6.9 |
| 500 | 7.72 | 19.08 | 34.47 | 26.92 | 114.1 | 122.9 | 1.013 | 0 | 0 |

| STATION | DATE | TIME | LATITUDE | LONGITUDE | D |
|---|---|---|---|---|---|
| H 054 | NOV 3, 1963 | 0600-0650 | 28° 22.0'S | 132° 03.0'W | 33 |

OBSERVED AND COMPUTED VALUES AT OBSERVED DEPTHS

| Z (m) | T (°C) | Cl (‰) | S (‰) | $O_2$ (ml/L) | $\sigma_T$ (gm/L) | $\delta_T$ (cl/L) | AOU (ml/L) | $PO_4$ (μg at./L) | $NO_3$ (μg at./L) | $SiO_4$ (μg at./L) | $NO_2$ (μg at./L) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 0 | 19.80 | 19.67 | 35.53 | 5.26 | 25.24 | 273.8 | -.24 | .19 | .7 | .7 | .10 |
| 24 | 19.96 | 19.64 | 35.48 | 5.13 | 25.16 | 281.7 | -.13 | .16 | .2 | .7 | .05 |
| 47 | 19.71 | 19.64 | 35.48 | 5.07 | 25.22 | 275.5 | -.04 | .16 | .2 | .6 | .04 |
| 70 | 19.51 | 19.63 | 35.46 | 5.11 | 25.26 | 271.8 | -.06 | .19 | .4 | .6 | .03 |
| 94 | 19.33 | 19.61 | 35.43 | 5.17 | 25.28 | 270.0 | -.11 | .20 | .5 | .7 | .08 |
| 141 | 18.17 | 19.60 | 35.41 | 5.12 | 25.56 | 243.4 | .05 | .18 | .5 | .7 | .06 |
| 251 | 15.28 | 19.49 | 35.21 | 4.77 | 26.09 | 193.1 | .70 | .30 | 4.7 | 1.2 | .03 |
| 348 | 12.98 | 19.35 | 34.96 | 4.53 | 26.38 | 165.3 | 1.21 | .51 | 11.0 | 2.6 | .03 |
| 435 | 10.06 | 19.18 | 34.65 | 4.57 | 26.69 | 136.3 | 1.56 | .88 | 19.4 | -0 | .02 |
| 651 | 6.41 | 19.00 | 34.33 | 5.22 | 26.99 | 107.8 | 1.47 | 1.25 | 28.3 | -0 | .03 |

INTERPOLATED AND COMPUTED VALUES AT STANDARD DEPTHS

| Z (m) | T (°C) | Cl (‰) | S (‰) | $\sigma_T$ (gm/L) | $\delta_T$ (cl/T) | $\delta$ (cl/T) | $\Delta D_{Z/0}$ (dyn m) | $\Delta D_{Z/Z\,MAX}$ (dyn m) | $Q_Z$ (m-dynm) |
|---|---|---|---|---|---|---|---|---|---|
| 0 | 19.80 | 19.67 | 35.53 | 25.24 | 273.8 | 273.9 | 0 | 1.296 | 376.2 |
| 10 | 19.92 | 19.65 | 35.49 | 25.18 | 279.7 | 280.2 | .028 | 1.269 | 363.4 |
| 20 | 19.95 | 19.64 | 35.48 | 25.16 | 281.3 | 282.1 | .056 | 1.241 | 350.8 |
| 30 | 19.91 | 19.64 | 35.48 | 25.17 | 280.5 | 281.7 | .084 | 1.212 | 338.6 |
| 50 | 19.69 | 19.64 | 35.48 | 25.23 | 275.1 | 276.9 | .140 | 1.157 | 314.9 |
| 75 | 19.48 | 19.63 | 35.46 | 25.26 | 271.5 | 274.2 | .209 | 1.088 | 286.8 |
| 100 | 19.22 | 19.61 | 35.42 | 25.30 | 267.6 | 271.2 | .277 | 1.019 | 260.5 |
| 150 | 18.00 | 19.59 | 35.39 | 25.59 | 240.3 | 245.4 | .406 | .890 | 212.7 |
| 200 | 16.88 | 19.55 | 35.31 | 25.80 | 220.4 | 226.9 | .524 | .772 | 171.2 |
| 250 | 15.32 | 19.49 | 35.21 | 26.08 | 193.7 | 201.3 | .631 | .665 | 135.2 |
| 300 | 14.22 | 19.42 | 35.09 | 26.23 | 179.9 | 188.6 | .729 | .568 | 104.4 |
| 400 | 11.22 | 19.24 | 34.76 | 26.56 | 147.8 | 157.5 | .902 | .395 | 56.3 |
| 500 | 8.80 | 19.11 | 34.52 | 26.79 | 126.4 | 136.3 | 1.049 | .248 | 24.2 |
| 600 | 7.15 | 19.03 | 34.37 | 26.93 | 113.6 | 123.5 | 1.179 | .118 | 5.9 |
| 700 | 5.75 | 18.98 | 34.29 | 27.04 | 102.7 | 112.2 | 1.296 | 0 | 0 |

| STATION | DATE | TIME | LATITUDE | LONGITUDE | D |
|---|---|---|---|---|---|
| H 057 | NOV 4, 1963 | 1200-1250 | 30° 29.0'S | 128° 31.0'W | 36 |

OBSERVED AND COMPUTED VALUES AT OBSERVED DEPTHS

| Z (m) | T (°C) | Cl (‰) | S (‰) | $O_2$ (ml/L) | $\sigma_T$ (gm/L) | $\delta_T$ (cl/L) | AOU (ml/L) | $PO_4$ (μg at./L) | $NO_3$ (μg at./L) | $SiO_4$ (μg at./L) | $NO_2$ (μg at./L) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 0 | 19.40 | 19.55 | 35.32 | 5.27 | 25.18 | 279.6 | -.21 | .16 | .4 | -0 | .04 |
| 24 | 19.13 | 19.55 | 35.32 | 5.27 | 25.25 | 273.0 | -.19 | .16 | .2 | -0 | .03 |
| 49 | 18.90 | 19.56 | 35.34 | 4.74 | 25.32 | 266.1 | .36 | .15 | .3 | -0 | .02 |
| 73 | 18.56 | 19.57 | 35.35 | 5.48 | 25.42 | 256.6 | -.34 | .15 | .1 | -0 | .03 |
| 97 | 18.20 | 19.53 | 35.28 | 5.32 | 25.46 | 253.3 | -.15 | .14 | .1 | -0 | .03 |
| 146 | 17.18 | 19.51 | 35.25 | 5.30 | 25.68 | 232.2 | -.03 | .12 | .5 | -0 | .04 |
| 319 | 12.07 | 19.29 | 34.85 | 4.60 | 26.48 | 156.3 | 1.26 | .60 | 13.4 | -0 | .02 |
| 430 | 9.00 | 19.11 | 34.52 | 4.74 | 26.77 | 128.9 | 1.54 | 1.00 | 21.0 | -0 | .03 |
| 520 | 7.24 | 19.03 | 34.38 | 5.30 | 26.92 | 114.5 | 1.25 | 1.16 | 25.6 | -0 | .02 |
| 710 | 6.02 | 18.99 | 34.31 | 5.21 | 27.02 | 104.4 | 1.54 | 1.26 | 28.9 | -0 | .03 |

INTERPOLATED AND COMPUTED VALUES AT STANDARD DEPTHS

| Z (m) | T (°C) | Cl (‰) | S (‰) | $\sigma_T$ (gm/L) | $\delta_T$ (cl/T) | $\delta$ (cl/T) | $\Delta D_{Z/0}$ (dyn m) | $\Delta D_{Z/Z\,MAX}$ (dyn m) | $Q_Z$ (m-dynm) |
|---|---|---|---|---|---|---|---|---|---|
| 0 | 19.40 | 19.55 | 35.32 | 25.18 | 279.6 | 279.7 | 0 | 1.230 | 356.1 |
| 10 | 19.33 | 19.55 | 35.32 | 25.20 | 277.9 | 278.3 | .028 | 1.202 | 343.9 |
| 20 | 19.21 | 19.55 | 35.32 | 25.23 | 274.9 | 275.7 | .056 | 1.174 | 332.1 |
| 30 | 19.07 | 19.55 | 35.32 | 25.26 | 271.7 | 272.6 | .083 | 1.147 | 320.5 |
| 50 | 18.89 | 19.56 | 35.34 | 25.32 | 265.8 | 267.6 | .137 | 1.093 | 298.1 |
| 75 | 18.53 | 19.57 | 35.35 | 25.42 | 256.3 | 259.0 | .203 | 1.027 | 271.6 |
| 100 | 18.15 | 19.53 | 35.28 | 25.47 | 252.2 | 255.7 | .267 | .962 | 246.7 |
| 150 | 17.09 | 19.51 | 35.24 | 25.69 | 230.8 | 235.8 | .390 | .840 | 201.7 |
| 200 | 15.78 | 19.44 | 35.11 | 25.90 | 210.8 | 217.0 | .503 | .726 | 162.5 |
| 250 | 14.04 | 19.35 | 34.96 | 26.17 | 185.6 | 192.7 | .606 | .624 | 128.7 |
| 300 | 12.57 | 19.30 | 34.87 | 26.40 | 163.7 | 171.6 | .697 | .533 | 99.8 |
| 400 | 9.74 | 19.15 | 34.59 | 26.69 | 135.6 | 144.2 | .855 | .375 | 54.4 |
| 500 | 7.60 | 19.04 | 34.40 | 26.88 | 117.5 | 126.2 | .990 | .240 | 23.7 |
| 600 | 6.68 | 19.01 | 34.34 | 26.97 | 109.7 | 119.2 | 1.113 | .117 | 5.9 |
| 700 | 6.08 | 18.99 | 34.31 | 27.02 | 104.8 | 114.8 | 1.230 | 0 | 0 |

H 059

| STATION | DATE | TIME | LATITUDE | LONGITUDE | D |
|---|---|---|---|---|---|
| H 059 | NOV 5, 1963 | 0600-0710 | 30° 58.0'S | 126° 52.0'W | 33 |

OBSERVED AND COMPUTED VALUES AT OBSERVED DEPTHS

| Z (m) | T (°C) | Cl (‰) | S (‰) | $O_2$ (ml/L) | $\sigma_T$ (gm/L) | $\delta_T$ (cl/L) | AOU (ml/L) | $PO_4$ (µg at./L) | $NO_3$ (µg at./L) | $SiO_4$ (µg at./L) | $NO_2$ (µg at./L) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 0 | 18.96 | 19.57 | 35.35 | 5.28 | 25.32 | 266.2 | -.18 | .11 | 2.0 | 1.3 | .07 |
| 25 | 19.18 | 19.55 | 35.32 | 5.32 | 25.24 | 274.2 | -.24 | .08 | .2 | 1.7 | .01 |
| 50 | 18.91 | 19.55 | 35.32 | 5.26 | 25.31 | 267.6 | -.16 | .07 | .1 | 2.3 | .01 |
| 75 | 18.41 | 19.54 | 35.30 | 5.53 | 25.42 | 256.9 | -.38 | .08 | .2 | 1.7 | .02 |
| 100 | 18.18 | 19.53 | 35.28 | 5.32 | 25.46 | 252.8 | -.15 | .07 | .2 | 1.5 | -0 |
| 149 | 17.27 | 19.50 | 35.23 | 5.45 | 25.64 | 235.6 | -.19 | .08 | .5 | 1.2 | .03 |
| 280 | 13.32 | 19.34 | 34.94 | 4.73 | 26.30 | 173.2 | .97 | -0 | -0 | -0 | -0 |
| 375 | 10.63 | 19.22 | 34.72 | 4.68 | 26.64 | 140.4 | 1.37 | .98 | -0 | -0 | -0 |
| 448 | 8.46 | 19.13 | 34.56 | 4.81 | 26.88 | 118.2 | 1.55 | -0 | 23.1 | 6.8 | .02 |
| 619 | 6.41 | 19.00 | 34.33 | 5.39 | 26.99 | 107.8 | 1.30 | 1.08 | 27.0 | 9.7 | .01 |

INTERPOLATED AND COMPUTED VALUES AT STANDARD DEPTHS

| Z (m) | T (°C) | Cl (‰) | S (‰) | $\sigma_T$ (gm/L) | $\delta_T$ (cl/T) | $\delta$ (cl/T) | $\Delta D_{Z/0}$ (dyn m) | $\Delta D_{Z/Z MAX}$ (dyn m) | $Q_Z$ (m-dynm) |
|---|---|---|---|---|---|---|---|---|---|
| 0 | 18.96 | 19.57 | 35.35 | 25.32 | 266.2 | 266.3 | 0 | 1.111 | 278.3 |
| 10 | 19.12 | 19.56 | 35.33 | 25.26 | 272.1 | 272.6 | .027 | 1.084 | 267.3 |
| 20 | 19.17 | 19.55 | 35.32 | 25.24 | 273.7 | 274.5 | .054 | 1.057 | 256.6 |
| 30 | 19.14 | 19.55 | 35.32 | 25.24 | 273.3 | 274.4 | .082 | 1.029 | 246.1 |
| 50 | 18.91 | 19.55 | 35.32 | 25.30 | 267.6 | 269.5 | .136 | .975 | 226.1 |
| 75 | 18.41 | 19.54 | 35.30 | 25.42 | 256.9 | 259.6 | .202 | .909 | 202.6 |
| 100 | 18.18 | 19.53 | 35.28 | 25.46 | 252.8 | 256.3 | .267 | .844 | 180.7 |
| 150 | 17.25 | 19.50 | 35.23 | 25.64 | 235.2 | 240.2 | .391 | .720 | 141.6 |
| 200 | 15.84 | 19.43 | 35.10 | 25.88 | 212.7 | 218.9 | .506 | .605 | 108.4 |
| 250 | 14.16 | 19.36 | 34.98 | 26.16 | 186.5 | 193.7 | .609 | .502 | 80.7 |
| 300 | 12.68 | 19.31 | 34.88 | 26.38 | 165.4 | 173.4 | .701 | .410 | 57.9 |
| 400 | 9.84 | 19.18 | 34.66 | 26.73 | 132.3 | 141.0 | .858 | .253 | 24.7 |
| 500 | 7.76 | 19.08 | 34.47 | 26.91 | 114.7 | 123.6 | .990 | .121 | 6.0 |
| 600 | 6.61 | 19.01 | 34.34 | 26.98 | 108.8 | 118.1 | 1.111 | 0 | 0 |

H 062

| STATION | DATE | TIME | LATITUDE | LONGITUDE | D |
|---|---|---|---|---|---|
| H 062 | NOV 6, 1963 | 1200-1250 | 32° 25.0'S | 126° 09.0'W | 40 |

OBSERVED AND COMPUTED VALUES AT OBSERVED DEPTHS

| Z (m) | T (°C) | Cl (‰) | S (‰) | $O_2$ (ml/L) | $\sigma_T$ (gm/L) | $\delta_T$ (cl/L) | AOU (ml/L) | $PO_4$ (µg at./L) | $NO_3$ (µg at./L) | $SiO_4$ (µg at./L) | $NO_2$ (µg at./L) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 0 | 18.08 | 19.52 | 35.26 | 5.43 | 25.47 | 251.7 | -.25 | .12 | .5 | 1.2 | .07 |
| 22 | 17.94 | 19.47 | 35.17 | 5.33 | 25.44 | 255.0 | -.13 | .08 | .1 | 1.2 | .02 |
| 44 | 17.79 | 19.50 | 35.23 | 5.53 | 25.52 | 247.6 | -.32 | .08 | .2 | 1.1 | .03 |
| 66 | 17.80 | 19.48 | 35.19 | 5.60 | 25.49 | 250.4 | -.39 | .07 | .2 | 1.2 | .05 |
| 88 | 17.51 | 19.48 | 35.19 | 5.46 | 25.56 | 243.7 | -.22 | .09 | .2 | 1.4 | .02 |
| 132 | 16.72 | 19.43 | 35.10 | 5.56 | 25.68 | 232.3 | -.24 | .09 | .3 | 1.2 | .04 |
| 225 | 14.56 | 19.40 | 35.05 | 4.82 | 26.12 | 190.0 | .73 | .30 | 5.2 | 1.9 | .03 |
| 319 | 12.31 | 19.31 | 34.88 | 4.66 | 26.46 | 158.1 | 1.17 | .55 | 12.5 | 3.4 | .07 |
| 382 | 9.92 | 19.16 | 34.61 | 4.69 | 26.68 | 136.7 | 1.46 | .76 | 18.7 | 5.3 | .02 |
| 552 | 6.96 | 18.97 | 34.27 | 5.32 | 26.87 | 118.9 | 1.28 | 1.24 | 26.2 | 8.5 | .02 |

INTERPOLATED AND COMPUTED VALUES AT STANDARD DEPTHS

| Z (m) | T (°C) | Cl (‰) | S (‰) | $\sigma_T$ (gm/L) | $\delta_T$ (cl/T) | $\delta$ (cl/T) | $\Delta D_{Z/0}$ (dyn m) | $\Delta D_{Z/Z MAX}$ (dyn m) | $Q_Z$ (m-dynm) |
|---|---|---|---|---|---|---|---|---|---|
| 0 | 18.08 | 19.52 | 35.26 | 25.47 | 251.7 | 251.9 | 0 | 1.096 | 282.0 |
| 10 | 18.04 | 19.49 | 35.22 | 25.44 | 254.2 | 254.7 | .025 | 1.070 | 271.2 |
| 20 | 17.96 | 19.47 | 35.18 | 25.44 | 254.9 | 255.7 | .051 | 1.045 | 260.6 |
| 30 | 17.90 | 19.48 | 35.19 | 25.46 | 253.0 | 254.1 | .076 | 1.019 | 250.3 |
| 50 | 17.79 | 19.49 | 35.22 | 25.51 | 248.5 | 250.2 | .127 | .969 | 230.4 |
| 75 | 17.70 | 19.48 | 35.19 | 25.51 | 248.1 | 250.7 | .189 | .906 | 207.0 |
| 100 | 17.34 | 19.47 | 35.17 | 25.58 | 241.1 | 244.5 | .251 | .844 | 185.1 |
| 150 | 16.41 | 19.42 | 35.09 | 25.74 | 226.3 | 231.1 | .370 | .726 | 145.8 |
| 200 | 15.31 | 19.41 | 35.06 | 25.97 | 204.7 | 210.8 | .481 | .615 | 112.3 |
| 250 | 14.05 | 19.38 | 35.01 | 26.20 | 182.5 | 189.7 | .581 | .515 | 84.1 |
| 300 | 12.85 | 19.33 | 34.92 | 26.38 | 165.4 | 173.5 | .672 | .424 | 60.6 |
| 400 | 9.55 | 19.13 | 34.56 | 26.71 | 134.4 | 142.9 | .830 | .266 | 26.1 |
| 500 | 7.76 | 19.01 | 34.35 | 26.82 | 123.7 | 132.6 | .968 | .128 | 6.4 |
| 600 | 6.29 | 18.94 | 34.21 | 26.91 | 114.9 | 123.7 | 1.096 | 0 | 0 |

| STATION | DATE | TIME | LATITUDE | LONGITUDE | D |
|---|---|---|---|---|---|
| H 064 | NOV 7, 1963 | 0605-0650 | 32° 47.0'S | 123° 20.0'W | 32 |

OBSERVED AND COMPUTED VALUES AT OBSERVED DEPTHS

| Z (m) | T (°C) | Cl (‰) | S (‰) | $O_2$ (ml/L) | $\sigma_T$ (gm/L) | $\delta_T$ (cl/L) | AOU (ml/L) | $PO_4$ | $NO_3$ (μg at./L) | $SiO_4$ | $NO_2$ |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 0 | 16.90 | 19.37 | 34.99 | 5.63 | 25.55 | 244.3 | -.32 | .09 | .4 | .9 | .07 |
| 25 | 16.94 | 19.38 | 35.01 | 5.48 | 25.56 | 243.9 | -.18 | .07 | .2 | 1.4 | .03 |
| 49 | 16.81 | 19.38 | 35.01 | 5.63 | 25.59 | 240.9 | -.31 | .07 | .2 | 1.5 | .05 |
| 74 | 16.83 | 19.39 | 35.03 | 5.78 | 25.60 | 240.1 | -.47 | .07 | .2 | 1.0 | .03 |
| 99 | 16.64 | 19.40 | 35.05 | 5.56 | 25.65 | 234.5 | -.23 | .08 | .1 | 1.0 | .05 |
| 148 | 16.32 | 19.48 | 35.19 | 5.25 | 25.84 | 216.9 | .11 | .11 | 1.1 | 1.3 | .10 |
| 219 | 14.11 | 19.35 | 34.96 | 4.79 | 26.15 | 187.5 | .82 | .28 | 5.2 | 1.2 | .04 |
| 315 | 999.00 | 19.21 | 34.70 | 4.84 | 999.00 | 999.0 | 999.00 | .60 | 13.6 | 3.6 | .07 |
| 404 | 8.42 | 19.20 | 34.69 | 4.95 | 26.98 | 106.2 | 1.41 | 1.01 | 23.3 | 7.3 | .03 |
| 624 | 6.45 | 19.02 | 34.36 | 5.44 | 27.01 | 105.6 | 1.24 | 1.23 | 27.2 | 9.4 | .03 |

INTERPOLATED AND COMPUTED VALUES AT STANDARD DEPTHS

| Z (m) | T (°C) | Cl (‰) | S (‰) | $\sigma_T$ (gm/L) | $\delta_T$ (cl/T) | $\delta$ (cl/T) | $\Delta D_{Z/0}$ (dyn m) | $\Delta D_{Z/Z\,MAX}$ (dyn m) | $Q_Z$ (m-dyn m) |
|---|---|---|---|---|---|---|---|---|---|
| 0 | 16.90 | 19.37 | 34.99 | 25.55 | 244.3 | 244.4 | 0 | 1.008 | 252.2 |
| 10 | 16.93 | 19.38 | 35.00 | 25.55 | 244.2 | 244.6 | .024 | .983 | 242.3 |
| 20 | 16.94 | 19.38 | 35.01 | 25.55 | 244.0 | 244.8 | .049 | .959 | 232.6 |
| 30 | 16.92 | 19.38 | 35.01 | 25.56 | 243.5 | 244.6 | .073 | .934 | 223.1 |
| 50 | 16.81 | 19.38 | 35.01 | 25.58 | 240.9 | 242.6 | .122 | .885 | 204.9 |
| 75 | 16.82 | 19.39 | 35.03 | 25.60 | 239.9 | 242.4 | .183 | .825 | 183.5 |
| 100 | 16.63 | 19.40 | 35.05 | 25.65 | 234.3 | 237.5 | .243 | .765 | 163.7 |
| 150 | 16.28 | 19.48 | 35.19 | 25.84 | 216.2 | 221.0 | .357 | .650 | 128.3 |
| 200 | 14.68 | 19.38 | 35.01 | 26.07 | 195.0 | 200.9 | .463 | .545 | 98.4 |
| 250 | 12.88 | 19.30 | 34.86 | 26.33 | 170.3 | 177.1 | .557 | .450 | 73.5 |
| 300 | 11.19 | 19.24 | 34.76 | 26.58 | 146.8 | 154.0 | .640 | .367 | 53.1 |
| 400 | 8.51 | 19.20 | 34.69 | 26.97 | 109.5 | 117.3 | .776 | .232 | 23.1 |
| 500 | 7.45 | 19.11 | 34.52 | 27.00 | 106.9 | 115.6 | .892 | .115 | 5.8 |
| 600 | 6.63 | 19.03 | 34.39 | 27.01 | 105.9 | 115.2 | 1.008 | 0 | 0 |

| STATION | DATE | TIME | LATITUDE | LONGITUDE | D |
|---|---|---|---|---|---|
| H 067 | NOV 8, 1963 | 1200-1250 | 34° 46.0'S | 119° 52.0'W | 45 |

OBSERVED AND COMPUTED VALUES AT OBSERVED DEPTHS

| Z (m) | T (°C) | Cl (‰) | S (‰) | $O_2$ (ml/L) | $\sigma_T$ (gm/L) | $\delta_T$ (cl/L) | AOU (ml/L) | $PO_4$ | $NO_3$ (μg at./L) | $SiO_4$ | $NO_2$ |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 0 | 16.60 | 19.37 | 34.99 | 5.60 | 25.62 | 237.6 | -.26 | .13 | .2 | .5 | .08 |
| 24 | 16.44 | 19.36 | 34.97 | 5.54 | 25.64 | 235.3 | -.18 | .10 | .1 | .5 | .02 |
| 49 | 16.33 | 19.37 | 34.99 | 5.70 | 25.68 | 231.6 | -.33 | .11 | .1 | .5 | .02 |
| 73 | 16.36 | 19.36 | 34.97 | 5.79 | 25.66 | 233.6 | -.43 | .10 | .1 | .5 | .04 |
| 97 | 16.36 | 19.38 | 35.01 | 5.61 | 25.69 | 230.9 | -.25 | .08 | .2 | .5 | .03 |
| 146 | 16.02 | 19.38 | 35.01 | 5.56 | 25.77 | 223.5 | -.16 | .13 | 1.2 | .8 | .08 |
| 250 | 13.11 | 19.24 | 34.76 | 5.60 | 26.20 | 182.4 | .13 | .35 | 8.1 | 1.6 | .04 |
| 350 | 10.31 | 19.12 | 34.54 | 5.00 | 26.56 | 148.4 | 1.10 | .75 | 17.1 | 3.3 | .03 |
| 437 | 8.20 | 19.05 | 34.42 | 4.89 | 26.81 | 125.1 | 1.52 | .93 | 24.6 | 6.0 | -0 |
| 653 | 6.25 | 19.02 | 34.36 | 5.52 | 27.04 | 103.1 | 1.19 | 1.31 | 28.3 | 9.6 | .03 |

INTERPOLATED AND COMPUTED VALUES AT STANDARD DEPTHS

| Z (m) | T (°C) | Cl (‰) | S (‰) | $\sigma_T$ (gm/L) | $\delta_T$ (cl/T) | $\delta$ (cl/T) | $\Delta D_{Z/0}$ (dyn m) | $\Delta D_{Z/Z\,MAX}$ (dyn m) | $Q_Z$ (m-dyn m) |
|---|---|---|---|---|---|---|---|---|---|
| 0 | 16.60 | 19.37 | 34.99 | 25.62 | 237.6 | 237.7 | 0 | 1.179 | 349.1 |
| 10 | 16.56 | 19.37 | 34.99 | 25.63 | 237.0 | 237.4 | .024 | 1.155 | 337.5 |
| 20 | 16.49 | 19.36 | 34.98 | 25.64 | 236.0 | 236.7 | .047 | 1.131 | 326.0 |
| 30 | 16.42 | 19.36 | 34.98 | 25.65 | 234.7 | 235.7 | .071 | 1.108 | 314.9 |
| 50 | 16.33 | 19.37 | 34.99 | 25.68 | 231.7 | 233.4 | .118 | 1.061 | 293.2 |
| 75 | 16.36 | 19.36 | 34.98 | 25.66 | 233.4 | 235.9 | .177 | 1.002 | 267.4 |
| 100 | 16.35 | 19.38 | 35.01 | 25.69 | 230.6 | 233.8 | .235 | .943 | 243.1 |
| 150 | 15.95 | 19.38 | 35.00 | 25.78 | 222.5 | 227.2 | .351 | .828 | 198.8 |
| 200 | 14.90 | 19.32 | 34.91 | 25.94 | 206.9 | 212.9 | .461 | .718 | 160.1 |
| 250 | 13.11 | 19.24 | 34.76 | 26.20 | 182.4 | 189.2 | .561 | .618 | 126.7 |
| 300 | 11.71 | 19.17 | 34.64 | 26.38 | 165.4 | 172.9 | .652 | .527 | 98.1 |
| 400 | 9.04 | 19.07 | 34.46 | 26.71 | 134.4 | 142.5 | .809 | .369 | 53.3 |
| 500 | 7.55 | 19.04 | 34.39 | 26.88 | 117.8 | 126.5 | .944 | .235 | 23.1 |
| 600 | 6.66 | 19.02 | 34.37 | 26.99 | 107.8 | 117.1 | 1.066 | .113 | 5.7 |
| 700 | 5.91 | 19.02 | 34.36 | 27.08 | 99.3 | 109.1 | 1.179 | 0 | 0 |

| STATION | DATE | TIME | LATITUDE | LONGITUDE | D |
|---|---|---|---|---|---|
| H 069 | NOV 9, 1963 | 0605-0720 | 35° 46.0'S | 116° 47.0'W | 32 |

OBSERVED AND COMPUTED VALUES AT OBSERVED DEPTHS

| Z (m) | T (°C) | Cl (‰) | S (‰) | $O_2$ (ml/L) | $\sigma_T$ (gm/L) | $\delta_T$ (cl/L) | AOU (ml/L) | $PO_4$ (µg at./L) | $NO_3$ (µg at./L) | $SiO_4$ (µg at./L) | $NO_2$ (µg at./L) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 0 | 15.20 | 19.19 | 34.67 | 5.80 | 25.69 | 231.0 | -.30 | .14 | 1.0 | .8 | .08 |
| 24 | 15.13 | 19.19 | 34.67 | 5.69 | 25.71 | 229.5 | -.18 | .13 | .3 | 1.3 | 0 |
| 48 | 15.05 | 19.18 | 34.65 | 5.88 | 25.71 | 229.2 | -.36 | .13 | .4 | 1.6 | .01 |
| 71 | 15.06 | 19.20 | 34.69 | 5.91 | 25.74 | 226.7 | -.40 | .10 | .5 | .8 | .04 |
| 95 | 15.15 | 19.20 | 34.69 | 5.84 | 25.72 | 228.6 | -.34 | .12 | .5 | 1.1 | .01 |
| 143 | 14.95 | 19.18 | 34.65 | 5.78 | 25.73 | 227.1 | -.25 | .14 | .3 | 1.0 | .01 |
| 283 | 10.99 | 19.11 | 34.52 | 5.23 | 26.43 | 161.1 | .78 | .57 | 10.3 | 2.1 | .07 |
| 425 | 7.39 | 19.08 | 34.47 | 5.32 | 26.97 | 109.8 | 1.21 | .99 | 20.7 | 7.1 | .02 |
| 512 | 6.80 | 19.06 | 34.43 | 5.50 | 27.02 | 104.7 | 1.12 | .99 | 20.9 | 7.6 | .01 |
| 706 | 6.00 | 19.03 | 34.38 | 5.54 | 27.08 | 98.7 | 1.21 | 1.22 | 22.1 | 10.4 | .01 |

INTERPOLATED AND COMPUTED VALUES AT STANDARD DEPTHS

H 069

| Z (m) | T (°C) | Cl (‰) | S (‰) | $\sigma_T$ (gm/L) | $\delta_T$ (cl/T) | $\delta$ (cl/T) | $\Delta D_{Z/0}$ (dyn m) | $\Delta D_{Z/Z\,MAX}$ (dyn m) | $Q_Z$ (m-dynm) |
|---|---|---|---|---|---|---|---|---|---|
| 0 | 15.20 | 19.19 | 34.67 | 25.69 | 231.0 | 231.1 | 0 | 1.123 | 327.3 |
| 10 | 15.18 | 19.19 | 34.67 | 25.69 | 230.6 | 231.0 | .023 | 1.100 | 316.2 |
| 20 | 15.15 | 19.19 | 34.67 | 25.70 | 229.9 | 230.7 | .046 | 1.077 | 305.3 |
| 30 | 15.11 | 19.19 | 34.66 | 25.71 | 229.4 | 230.5 | .069 | 1.053 | 294.6 |
| 50 | 15.05 | 19.18 | 34.65 | 25.71 | 229.0 | 230.6 | .115 | 1.007 | 274.0 |
| 75 | 15.08 | 19.20 | 34.69 | 25.73 | 227.1 | 229.5 | .173 | .950 | 249.6 |
| 100 | 15.14 | 19.20 | 34.68 | 25.72 | 228.5 | 231.6 | .230 | .892 | 226.5 |
| 150 | 14.83 | 19.18 | 34.64 | 25.75 | 225.2 | 229.7 | .346 | .777 | 184.8 |
| 200 | 13.55 | 19.14 | 34.58 | 25.98 | 203.7 | 209.4 | .456 | .667 | 148.7 |
| 250 | 11.85 | 19.12 | 34.53 | 26.27 | 175.5 | 181.9 | .553 | .569 | 117.8 |
| 300 | 10.47 | 19.10 | 34.50 | 26.50 | 153.8 | 160.7 | .639 | .484 | 91.5 |
| 400 | 7.93 | 19.08 | 34.47 | 26.38 | 117.5 | 124.8 | .782 | .341 | 50.2 |
| 500 | 6.88 | 19.06 | 34.44 | 27.01 | 105.3 | 113.4 | .901 | .222 | 22.1 |
| 600 | 6.41 | 19.04 | 34.40 | 27.05 | 101.8 | 110.8 | 1.013 | .110 | 5.5 |
| 700 | 6.02 | 19.03 | 34.38 | 27.08 | 98.9 | 108.8 | 1.123 | 0 | 0 |

| STATION | DATE | TIME | LATITUDE | LONGITUDE | D |
|---|---|---|---|---|---|
| H 071 | NOV 10, 1963 | 0610-0650 | 37° 02.0'S | 114° 41.0'W | 30 |

OBSERVED AND COMPUTED VALUES AT OBSERVED DEPTHS

| Z (m) | T (°C) | Cl (‰) | S (‰) | $O_2$ (ml/L) | $\sigma_T$ (gm/L) | $\delta_T$ (cl/L) | AOU (ml/L) | $PO_4$ (µg at./L) | $NO_3$ (µg at./L) | $SiO_4$ (µg at./L) | $NO_2$ (µg at./L) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 0 | 14.57 | 19.06 | 34.43 | 5.83 | 25.65 | 235.1 | -.25 | .20 | .7 | .8 | .07 |
| 25 | 14.52 | 19.05 | 34.42 | 5.95 | 25.64 | 235.4 | -.37 | .16 | .4 | 1.4 | .03 |
| 50 | 13.91 | 19.06 | 34.43 | 5.78 | 25.79 | 221.8 | -.13 | .16 | .4 | 1.6 | .04 |
| 74 | 14.23 | 19.04 | 34.40 | 5.82 | 25.69 | 230.8 | -.20 | .15 | .5 | 1.0 | .04 |
| 99 | 13.62 | 19.01 | 34.34 | 6.12 | 25.78 | 222.7 | -.43 | .19 | .9 | 1.2 | .10 |
| 149 | 12.27 | 19.01 | 34.34 | 5.75 | 26.05 | 197.1 | .10 | .39 | 4.7 | 1.2 | .44 |
| 198 | 11.49 | 19.05 | 34.42 | 5.49 | 26.25 | 177.8 | .46 | .50 | 8.9 | 1.7 | .11 |
| 290 | 8.72 | 19.05 | 34.42 | 5.21 | 26.73 | 132.8 | 1.12 | .87 | 18.6 | 3.9 | .02 |
| 385 | 7.19 | 19.04 | 34.40 | 5.39 | 26.94 | 112.5 | 1.17 | 1.09 | 22.7 | 7.4 | .01 |
| 586 | 6.18 | 19.03 | 34.38 | 5.74 | 27.06 | 100.9 | .98 | 1.18 | 23.9 | 10.1 | .01 |

H 071

INTERPOLATED AND COMPUTED VALUES AT STANDARD DEPTHS

| Z (m) | T (°C) | Cl (‰) | S (‰) | $\sigma_T$ (gm/L) | $\delta_T$ (cl/T) | $\delta$ (cl/T) | $\Delta D_{Z/0}$ (dyn m) | $\Delta D_{Z/Z\,MAX}$ (dyn m) | $Q_Z$ (m-dynm) |
|---|---|---|---|---|---|---|---|---|---|
| 0 | 14.57 | 19.06 | 34.43 | 25.65 | 235.1 | 235.2 | 0 | .945 | 238.4 |
| 10 | 14.56 | 19.06 | 34.43 | 25.64 | 235.3 | 235.7 | .024 | .921 | 229.1 |
| 20 | 14.54 | 19.05 | 34.42 | 25.64 | 235.4 | 236.1 | .047 | .898 | 220.0 |
| 30 | 14.45 | 19.05 | 34.42 | 25.66 | 233.5 | 234.4 | .071 | .874 | 211.1 |
| 50 | 13.91 | 19.06 | 34.43 | 25.79 | 221.8 | 223.3 | .116 | .829 | 194.1 |
| 75 | 14.21 | 19.04 | 34.40 | 25.69 | 230.6 | 232.8 | .173 | .772 | 174.1 |
| 100 | 13.60 | 19.01 | 34.34 | 25.78 | 222.3 | 225.2 | .231 | .714 | 155.5 |
| 150 | 12.76 | 19.01 | 34.34 | 26.05 | 196.8 | 200.8 | .337 | .608 | 127.4 |
| 200 | 11.44 | 19.05 | 34.41 | 26.26 | 177.0 | 181.9 | .433 | .512 | 94.4 |
| 250 | 9.91 | 19.04 | 34.40 | 26.52 | 152.1 | 157.7 | .518 | .427 | 71.0 |
| 300 | 8.54 | 19.05 | 34.41 | 26.75 | 130.3 | 136.2 | .591 | .354 | 51.4 |
| 400 | 7.10 | 19.04 | 34.39 | 26.95 | 111.4 | 118.1 | .718 | .227 | 22.4 |
| 500 | 6.56 | 19.03 | 34.38 | 27.01 | 105.3 | 113.0 | .834 | .111 | 5.5 |
| 600 | 6.12 | 19.03 | 34.38 | 27.07 | 100.3 | 109.0 | .945 | 0 | 0 |

| STATION | DATE | TIME | LATITUDE | LONGITUDE | D |
|---|---|---|---|---|---|
| H 074 | NOV 11, 1963 | 1200- | 39° 13.0'S | 111° 23.0'W | 26 |

OBSERVED AND COMPUTED VALUES AT OBSERVED DEPTHS

| Z (m) | T (°C) | Cl (‰) | S (‰) | $O_2$ (ml/L) | $\sigma_T$ (gm/L) | $\delta_T$ (cl/L) | AOU (ml/L) | $PO_4$ (µg at./L) | $NO_3$ (µg at./L) | $SiO_4$ (µg at./L) | $NO_2$ (µg at./L) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 0 | 14.35 | 19.03 | 34.38 | 5.95 | 25.65 | 234.6 | -.35 | .23 | 1.0 | .9 | .08 |
| 24 | 13.91 | 19.01 | 34.34 | 5.97 | 25.72 | 228.4 | -.31 | .20 | .9 | 1.4 | -0 |
| 48 | 13.46 | 18.99 | 34.31 | 6.03 | 25.78 | 222.2 | -.32 | .22 | 1.4 | 1.4 | .05 |
| 72 | 13.24 | 18.97 | 34.27 | 6.07 | 25.80 | 220.7 | -.33 | .23 | 1.9 | .8 | -0 |
| 96 | 12.99 | 18.99 | 34.31 | 5.96 | 25.88 | 213.2 | -.19 | .35 | 2.1 | 1.1 | -0 |
| 144 | 11.07 | 18.93 | 34.20 | 6.07 | 26.16 | 186.5 | -.06 | .48 | 7.7 | 1.2 | -0 |
| 213 | 9.95 | 19.03 | 34.38 | 5.44 | 26.50 | 154.5 | .71 | .69 | 13.6 | 1.6 | .02 |
| 292 | 8.11 | 19.01 | 34.34 | 5.37 | 26.76 | 129.2 | 1.05 | 1.01 | 20.4 | 4.7 | .01 |
| 371 | 7.11 | 19.03 | 34.38 | 5.65 | 26.94 | 112.8 | .92 | -0 | -0 | -0 | -0 |
| 559 | 6.27 | 19.03 | 34.38 | 5.80 | 27.05 | 102.0 | .91 | 1.28 | 25.2 | 9.8 | 0 |

INTERPOLATED AND COMPUTED VALUES AT STANDARD DEPTHS

| Z (m) | T (°C) | Cl (‰) | S (‰) | $\sigma_T$ (gm/L) | $\delta_T$ (cl/T) | $\delta$ (cl/T) | $\Delta D_{Z/0}$ (dyn m) | $\Delta D_{Z/Z\,MAX}$ (dyn m) | $Q_Z$ (m-dynm) |
|---|---|---|---|---|---|---|---|---|---|
| 0 | 14.35 | 19.03 | 34.38 | 25.65 | 234.6 | 234.7 | 0 | .912 | 232.2 |
| 10 | 14.23 | 19.02 | 34.37 | 25.67 | 233.0 | 233.4 | .023 | .888 | 223.2 |
| 20 | 14.04 | 19.02 | 34.35 | 25.70 | 230.2 | 230.9 | .047 | .865 | 214.4 |
| 30 | 13.82 | 19.01 | 34.34 | 25.73 | 227.2 | 228.2 | .070 | .842 | 205.9 |
| 50 | 13.44 | 18.99 | 34.30 | 25.78 | 222.1 | 223.6 | .115 | .797 | 189.5 |
| 75 | 13.21 | 18.97 | 34.27 | 25.81 | 219.9 | 222.0 | .170 | .741 | 170.3 |
| 100 | 12.86 | 18.99 | 34.30 | 25.90 | 211.4 | 214.1 | .225 | .687 | 152.4 |
| 150 | 10.95 | 18.94 | 34.22 | 26.19 | 183.2 | 186.8 | .325 | .586 | 120.6 |
| 200 | 10.13 | 19.01 | 34.35 | 26.44 | 159.7 | 164.2 | .413 | .499 | 93.5 |
| 250 | 9.02 | 19.02 | 34.35 | 26.63 | 141.7 | 146.8 | .491 | .421 | 70.5 |
| 300 | 8.00 | 19.01 | 34.35 | 26.78 | 127.4 | 132.9 | .561 | .351 | 51.2 |
| 400 | 6.96 | 19.03 | 34.38 | 26.96 | 110.8 | 117.4 | .686 | .226 | 22.4 |
| 500 | 6.50 | 19.03 | 34.38 | 27.02 | 105.0 | 112.6 | .801 | .111 | 5.5 |
| 600 | 6.12 | 19.03 | 34.38 | 27.07 | 100.2 | 108.9 | .912 | 0 | 0 |

| STATION | DATE | TIME | LATITUDE | LONGITUDE | D |
|---|---|---|---|---|---|
| H 076 | NOV 12, 1963 | 0555-0630 | 40° 07.0'S | 109° 22.0'W | 25 |

OBSERVED AND COMPUTED VALUES AT OBSERVED DEPTHS

| Z (m) | T (°C) | Cl (‰) | S (‰) | $O_2$ (ml/L) | $\sigma_T$ (gm/L) | $\delta_T$ (cl/L) | AOU (ml/L) | $PO_4$ (µg at./L) | $NO_3$ (µg at./L) | $SiO_4$ (µg at./L) | $NO_2$ (µg at./L) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 0 | 13.81 | 18.94 | 34.22 | 5.94 | 25.64 | 235.7 | -.27 | .33 | 3.0 | .6 | .09 |
| 25 | 13.52 | 18.91 | 34.16 | 6.02 | 25.66 | 234.0 | -.31 | .29 | 2.9 | .4 | .06 |
| 50 | 13.31 | 18.94 | 34.22 | 6.06 | 25.74 | 226.0 | -.33 | .29 | 2.8 | .5 | .06 |
| 75 | 13.38 | 18.96 | 34.25 | 6.12 | 25.76 | 224.7 | -.40 | .32 | 2.8 | .4 | .06 |
| 100 | 10.99 | 18.90 | 34.14 | 6.18 | 26.13 | 189.1 | -.16 | .49 | 7.5 | .5 | .19 |
| 150 | 10.50 | 18.94 | 34.22 | 5.87 | 26.27 | 175.5 | .22 | .61 | 10.7 | .8 | .42 |
| 199 | 9.54 | 19.02 | 34.36 | 5.30 | 26.55 | 149.3 | .91 | .88 | 15.8 | 2.3 | .02 |
| 297 | 7.52 | 19.04 | 34.40 | 5.35 | 26.89 | 117.0 | 1.16 | 1.06 | 21.5 | 5.4 | .01 |
| 394 | 6.78 | 19.02 | 34.36 | 5.44 | 26.97 | 109.8 | 1.19 | 1.31 | 22.8 | 7.3 | -0 |
| 598 | 5.99 | 19.02 | 34.36 | 5.69 | 27.07 | 100.0 | 1.07 | 1.29 | 24.6 | 9.8 | .01 |

INTERPOLATED AND COMPUTED VALUES AT STANDARD DEPTHS

| Z (m) | T (°C) | Cl (‰) | S (‰) | $\sigma_T$ (gm/L) | $\delta_T$ (cl/T) | $\delta$ (cl/T) | $\Delta D_{Z/0}$ (dyn m) | $\Delta D_{Z/Z\,MAX}$ (dyn m) | $Q_Z$ (m-dynm) |
|---|---|---|---|---|---|---|---|---|---|
| 0 | 13.81 | 18.94 | 34.22 | 25.64 | 235.7 | 235.8 | 0 | .881 | 224.5 |
| 10 | 13.74 | 18.93 | 34.20 | 25.64 | 235.3 | 235.7 | .024 | .857 | 215.8 |
| 20 | 13.62 | 18.92 | 34.18 | 25.65 | 234.6 | 235.3 | .047 | .834 | 207.3 |
| 30 | 13.49 | 18.91 | 34.17 | 25.67 | 233.0 | 233.9 | .071 | .810 | 199.1 |
| 50 | 13.31 | 18.94 | 34.22 | 25.74 | 226.0 | 227.5 | .117 | .764 | 183.3 |
| 75 | 13.38 | 18.96 | 34.25 | 25.76 | 224.7 | 226.8 | .174 | .707 | 165.0 |
| 100 | 10.99 | 18.90 | 34.14 | 26.13 | 189.1 | 191.6 | .226 | .655 | 147.9 |
| 150 | 10.50 | 18.94 | 34.22 | 26.27 | 175.5 | 179.1 | .318 | .562 | 117.5 |
| 200 | 9.51 | 19.02 | 34.36 | 26.55 | 148.9 | 153.2 | .402 | .479 | 91.4 |
| 250 | 8.39 | 19.03 | 34.37 | 26.74 | 130.9 | 135.7 | .474 | .407 | 69.3 |
| 300 | 7.49 | 19.04 | 34.40 | 26.89 | 116.7 | 122.0 | .538 | .343 | 50.5 |
| 400 | 6.75 | 19.02 | 34.36 | 26.97 | 109.5 | 115.8 | .657 | .224 | 22.2 |
| 500 | 6.33 | 19.02 | 34.36 | 27.02 | 104.2 | 111.7 | .771 | .110 | 5.5 |
| 600 | 5.98 | 19.02 | 34.36 | 27.07 | 99.9 | 108.4 | .881 | 0 | 0 |

H 078

| STATION | DATE | TIME | LATITUDE | LONGITUDE | D |
|---|---|---|---|---|---|
| H 078 | NOV 13, 1963 | 0600-0650 | 39° 10.0'S | 106° 43.0'W | 23 |

OBSERVED AND COMPUTED VALUES AT OBSERVED DEPTHS

| Z (m) | T (°C) | Cl (‰) | S (‰) | $O_2$ (ml/L) | $\sigma_T$ (gm/L) | $\delta_T$ (cl/L) | AOU (ml/L) | $PO_4$ (µg at./L) | $NO_3$ (µg at./L) | $SiO_4$ (µg at./L) | $NO_2$ (µg at./L) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 0 | 12.97 | 18.91 | 34.16 | 6.13 | 25.77 | 223.5 | -.36 | .50 | 4.9 | .5 | .13 |
| 25 | 12.82 | 18.91 | 34.16 | 6.13 | 25.80 | 220.6 | -.34 | .41 | 5.9 | .8 | .18 |
| 49 | 12.44 | 18.90 | 34.14 | 6.18 | 25.86 | 214.9 | -.34 | .42 | 4.8 | .5 | .18 |
| 74 | 11.29 | 18.92 | 34.18 | 6.31 | 26.10 | 191.6 | -.33 | .44 | 6.6 | .6 | .16 |
| 99 | 10.69 | 18.92 | 34.18 | 6.23 | 26.21 | 181.4 | -.17 | .77 | 9.3 | .8 | .24 |
| 148 | 9.86 | 18.95 | 34.23 | 5.84 | 26.40 | 163.8 | .33 | .65 | 12.9 | .9 | .21 |
| 220 | 8.05 | 19.03 | 34.38 | 5.91 | 26.80 | 125.7 | .52 | .92 | 17.7 | 2.8 | .06 |
| 313 | 6.99 | 19.04 | 34.40 | 5.64 | 26.97 | 109.9 | .95 | 1.23 | 22.7 | 6.4 | .01 |
| 422 | 6.49 | 19.06 | 34.43 | 5.59 | 27.06 | 100.7 | 1.08 | 1.47 | 23.7 | 7.9 | .01 |
| 610 | 5.81 | 19.02 | 34.36 | 5.81 | 27.09 | 97.8 | .98 | 1.28 | 24.7 | 10.5 | .01 |

INTERPOLATED AND COMPUTED VALUES AT STANDARD DEPTHS

| Z (m) | T (°C) | Cl (‰) | S (‰) | $\sigma_T$ (gm/L) | $\delta_T$ (cl/T) | $\delta$ (cl/T) | $\Delta D_{Z/0}$ (dyn m) | $\Delta D_{Z/Z MAX}$ (dyn m) | $Q_Z$ (m-dynm) |
|---|---|---|---|---|---|---|---|---|---|
| 0 | 12.97 | 18.91 | 34.16 | 25.77 | 223.5 | 223.6 | 0 | .825 | 212.2 |
| 10 | 12.93 | 18.91 | 34.16 | 25.78 | 222.7 | 223.1 | .022 | .803 | 204.0 |
| 20 | 12.87 | 18.91 | 34.16 | 25.79 | 221.6 | 222.2 | .045 | .780 | 196.1 |
| 30 | 12.77 | 18.91 | 34.16 | 25.81 | 219.8 | 220.7 | .067 | .758 | 188.4 |
| 50 | 12.41 | 18.90 | 34.14 | 25.87 | 214.2 | 215.6 | .110 | .715 | 173.7 |
| 75 | 11.26 | 18.92 | 34.18 | 26.11 | 191.1 | 193.1 | .161 | .664 | 156.5 |
| 100 | 10.67 | 16.92 | 34.18 | 26.22 | 180.9 | 183.4 | .209 | .616 | 140.5 |
| 150 | 9.80 | 18.95 | 34.24 | 26.41 | 162.5 | 165.8 | .296 | .529 | 111.8 |
| 200 | 8.49 | 19.01 | 34.34 | 26.70 | 134.8 | 138.8 | .372 | .453 | 87.3 |
| 250 | 7.67 | 19.03 | 34.38 | 26.86 | 119.9 | 124.5 | .438 | .387 | 66.3 |
| 300 | 7.12 | 19.04 | 34.39 | 26.95 | 111.8 | 116.8 | .498 | .327 | 48.4 |
| 400 | 6.58 | 19.06 | 34.43 | 27.04 | 102.4 | 108.6 | .611 | .214 | 21.4 |
| 500 | 6.18 | 19.04 | 34.40 | 27.08 | 99.4 | 106.7 | .718 | .107 | 5.3 |
| 600 | 5.84 | 19.02 | 34.36 | 27.09 | 98.0 | 106.3 | .825 | 0 | 0 |

H 081

| STATION | DATE | TIME | LATITUDE | LONGITUDE | D |
|---|---|---|---|---|---|
| H 081 | NOV 14, 1963 | 1200- | 38° 42.0'S | 102° 06.0'W | 26 |

OBSERVED AND COMPUTED VALUES AT OBSERVED DEPTHS

| Z (m) | T (°C) | Cl (‰) | S (‰) | $O_2$ (ml/L) | $\sigma_T$ (gm/L) | $\delta_T$ (cl/L) | AOU (ml/L) | $PO_4$ (µg at./L) | $NO_3$ (µg at./L) | $SiO_4$ (µg at./L) | $NO_2$ (µg at./L) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 0 | 13.49 | 18.90 | 34.14 | 6.13 | 25.65 | 234.7 | -.42 | .53 | 7.8 | .7 | .25 |
| 25 | 12.72 | 18.90 | 34.14 | 6.41 | 25.81 | 220.1 | -.61 | .41 | 7.4 | 1.1 | .13 |
| 50 | 12.39 | 18.87 | 34.09 | 6.13 | 25.83 | 217.9 | -.28 | .53 | 7.5 | 1.3 | .13 |
| 75 | 10.49 | 18.91 | 34.16 | 6.53 | 26.23 | 179.4 | -.44 | .92 | 8.2 | 1.0 | .13 |
| 100 | 10.14 | 18.92 | 34.18 | 6.26 | 26.31 | 172.3 | -.12 | .86 | 11.4 | 1.2 | .27 |
| 150 | 9.02 | 18.95 | 34.23 | 5.93 | 26.54 | 150.7 | .36 | .65 | 16.3 | 2.0 | .29 |
| 248 | 7.10 | 19.00 | 34.33 | 5.64 | 26.89 | 116.7 | .94 | 1.08 | 23.6 | 5.5 | .02 |
| 343 | 6.58 | 19.04 | 34.40 | 5.76 | 27.02 | 104.6 | .90 | 1.05 | 23.7 | 7.8 | .02 |
| 445 | 6.20 | 19.04 | 34.40 | 5.87 | 27.07 | 99.8 | .85 | 1.20 | 25.2 | 9.3 | .01 |
| 655 | 5.50 | 19.02 | 34.36 | 5.83 | 27.13 | 94.2 | 1.01 | 1.16 | 24.6 | 8.8 | .01 |

INTERPOLATED AND COMPUTED VALUES AT STANDARD DEPTHS

| Z (m) | T (°C) | Cl (‰) | S (‰) | $\sigma_T$ (gm/L) | $\delta_T$ (cl/T) | $\delta$ (cl/T) | $\Delta D_{Z/0}$ (dyn m) | $\Delta D_{Z/Z MAX}$ (dyn m) | $Q_Z$ (m-dynm) |
|---|---|---|---|---|---|---|---|---|---|
| 0 | 13.49 | 18.90 | 34.14 | 25.65 | 234.7 | 234.9 | 0 | .909 | 274.4 |
| 10 | 13.30 | 18.90 | 34.14 | 25.69 | 231.1 | 231.5 | .023 | .886 | 265.4 |
| 20 | 12.98 | 18.90 | 34.14 | 25.75 | 225.0 | 225.6 | .046 | .863 | 256.7 |
| 30 | 12.66 | 18.89 | 34.13 | 25.81 | 219.7 | 220.6 | .068 | .841 | 248.2 |
| 50 | 12.39 | 18.87 | 34.09 | 25.83 | 217.9 | 219.4 | .112 | .797 | 231.8 |
| 75 | 10.49 | 18.91 | 34.16 | 26.23 | 179.4 | 181.2 | .163 | .746 | 212.5 |
| 100 | 10.14 | 18.92 | 34.18 | 26.31 | 172.3 | 174.6 | .207 | .702 | 194.4 |
| 150 | 9.02 | 18.95 | 34.23 | 26.54 | 150.7 | 153.8 | .289 | .620 | 161.4 |
| 200 | 7.92 | 18.97 | 34.28 | 26.74 | 131.2 | 135.0 | .361 | .548 | 132.2 |
| 250 | 7.09 | 19.00 | 34.33 | 26.90 | 116.4 | 120.6 | .425 | .484 | 106.4 |
| 300 | 6.79 | 19.02 | 34.37 | 26.97 | 109.6 | 114.4 | .484 | .425 | 83.7 |
| 400 | 6.36 | 19.04 | 34.40 | 27.05 | 101.8 | 107.8 | .595 | .314 | 46.7 |
| 500 | 5.99 | 19.03 | 34.39 | 27.09 | 98.1 | 105.3 | .702 | .207 | 20.7 |
| 600 | 5.66 | 19.02 | 34.37 | 27.12 | 95.5 | 103.6 | .806 | .103 | 5.1 |
| 700 | 5.38 | 19.02 | 34.36 | 27.14 | 93.2 | 102.2 | .909 | 0 | 0 |

| STATION | DATE | TIME | LATITUDE | LONGITUDE | D |
|---|---|---|---|---|---|
| H 083 | NOV 15, 1963 | 0615-0700 | 38° 13.0'S | 101° 03.0'W | 22 |

| OBSERVED AND COMPUTED VALUES AT OBSERVED DEPTHS | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Z (m) | T (°C) | Cl (‰) | S (‰) | $O_2$ (ml/L) | $\sigma_T$ (gm/L) | $\delta_T$ (cl/L) | AOU (ml/L) | $PO_4$ | $NO_3$ | $SiO_4$ | $NO_2$ |
| | | | | | | | | (μg at./L) | | | |
| 0 | 13.70 | 18.90 | 34.14 | 6.04 | 25.61 | 238.8 | -.35 | .36 | 6.9 | 1.0 | .22 |
| 25 | 13.80 | 18.87 | 34.09 | 6.19 | 25.55 | 244.8 | -.51 | .71 | 4.7 | 1.1 | .11 |
| 50 | 13.44 | 18.86 | 34.07 | 6.09 | 25.61 | 239.1 | -.37 | .57 | 4.8 | 1.3 | .11 |
| 75 | 11.71 | 18.84 | 34.04 | 6.25 | 25.92 | 209.6 | -.31 | .43 | 6.9 | .9 | .18 |
| 100 | 11.33 | 18.99 | 34.31 | 6.10 | 26.20 | 183.0 | -.13 | .50 | 8.1 | 1.0 | .24 |
| 149 | 10.35 | 18.94 | 34.22 | 6.11 | 26.30 | 173.0 | -.00 | .52 | 11.1 | 1.2 | .36 |
| 207 | 9.25 | 18.94 | 34.22 | 5.78 | 26.49 | 155.5 | .48 | -0 | -0 | -0 | -0 |
| 308 | 7.27 | 19.00 | 34.33 | 5.54 | 26.87 | 118.9 | 1.01 | 1.03 | 22.1 | 5.0 | .03 |
| 403 | 6.35 | 19.02 | 34.36 | 5.46 | 27.02 | 104.4 | 1.24 | 1.16 | 26.7 | 8.9 | .02 |
| 604 | 5.61 | 19.03 | 34.38 | 5.73 | 27.13 | 94.1 | 1.09 | 1.39 | 27.6 | 10.9 | .02 |

H 08

| INTERPOLATED AND COMPUTED VALUES AT STANDARD DEPTHS | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Z (m) | T (°C) | Cl (‰) | S (‰) | $\sigma_T$ (gm/L) | $\delta_T$ (cl/T) | $\delta$ (cl/T) | $\Delta D_{Z/0}$ (dyn m) | $\Delta D_{Z/Z\,MAX}$ (dyn m) | $Q_Z$ (m-dynm) |
| 0 | 13.70 | 18.90 | 34.14 | 25.61 | 238.8 | 239.0 | 0 | .878 | 220.3 |
| 10 | 13.77 | 18.88 | 34.10 | 25.56 | 243.2 | 243.6 | .024 | .853 | 211.7 |
| 20 | 13.79 | 18.87 | 34.09 | 25.55 | 244.4 | 245.1 | .049 | .829 | 203.3 |
| 30 | 13.75 | 18.87 | 34.09 | 25.55 | 244.0 | 244.9 | .073 | .804 | 195.1 |
| 50 | 13.44 | 18.86 | 34.07 | 25.60 | 239.1 | 240.6 | .122 | .756 | 179.5 |
| 75 | 11.71 | 18.84 | 34.04 | 25.91 | 209.6 | 211.6 | .178 | .699 | 161.3 |
| 100 | 11.33 | 18.99 | 34.31 | 26.19 | 183.0 | 185.5 | .228 | .650 | 144.4 |
| 150 | 10.33 | 18.94 | 34.22 | 26.30 | 172.7 | 176.2 | .318 | .559 | 114.2 |
| 200 | 9.37 | 18.94 | 34.22 | 26.46 | 157.3 | 161.6 | .403 | .475 | 88.3 |
| 250 | 8.31 | 18.96 | 34.26 | 26.67 | 138.2 | 143.0 | .479 | .399 | 66.5 |
| 300 | 7.40 | 18.99 | 34.32 | 26.84 | 121.4 | 126.6 | .546 | .331 | 48.3 |
| 400 | 6.38 | 19.02 | 34.36 | 27.02 | 104.8 | 110.9 | .665 | .213 | 21.1 |
| 500 | 5.96 | 19.02 | 34.37 | 27.08 | 98.9 | 106.0 | .773 | .104 | 5.2 |
| 600 | 5.62 | 19.03 | 34.38 | 27.13 | 94.3 | 102.4 | .878 | 0 | 0 |

| STATION | DATE | TIME | LATITUDE | LONGITUDE | D |
|---|---|---|---|---|---|
| H 086 | NOV 16, 1963 | 1200-1238 | 34° 44.0'S | 101° 01.0'W | 28 |

| OBSERVED AND COMPUTED VALUES AT OBSERVED DEPTHS | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Z (m) | T (°C) | Cl (‰) | S (‰) | $O_2$ (ml/L) | $\sigma_T$ (gm/L) | $\delta_T$ (cl/L) | AOU (ml/L) | $PO_4$ | $NO_3$ | $SiO_4$ | $NO_2$ |
| | | | | | | | | (μg at./L) | | | |
| 0 | 16.08 | 19.02 | 34.36 | 5.80 | 25.26 | 272.2 | -.38 | .22 | 1.6 | .7 | .10 |
| 23 | 15.61 | 19.04 | 34.40 | 5.99 | 25.39 | 259.4 | -.53 | .16 | 1.0 | 1.1 | .03 |
| 46 | 15.27 | 19.04 | 34.40 | 5.93 | 25.47 | 252.2 | -.43 | .17 | .9 | .8 | .03 |
| 69 | 14.82 | 19.12 | 34.54 | 5.91 | 25.68 | 232.3 | -.36 | .14 | .4 | .7 | .03 |
| 92 | 14.18 | 19.09 | 34.49 | 5.86 | 25.77 | 223.2 | -.24 | .26 | 1.2 | .8 | .09 |
| 139 | 12.96 | 19.00 | 34.33 | 5.79 | 25.90 | 211.3 | -.02 | .31 | 3.4 | .7 | .27 |
| 290 | 8.37 | 19.02 | 34.36 | 5.14 | 26.74 | 131.6 | 1.24 | .97 | 21.2 | 3.5 | .03 |
| 388 | 6.69 | 19.04 | 34.40 | 5.47 | 27.01 | 106.0 | 1.17 | 1.11 | 25.4 | 7.3 | .01 |
| 476 | 6.23 | 19.05 | 34.42 | 5.64 | 27.08 | 98.8 | 1.07 | 1.11 | 26.2 | 9.3 | .01 |
| 675 | 5.45 | 19.01 | 34.34 | 5.68 | 27.12 | 95.0 | 1.17 | 1.26 | 27.5 | 11.8 | .01 |

H 08

| INTERPOLATED AND COMPUTED VALUES AT STANDARD DEPTHS | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Z (m) | T (°C) | Cl (‰) | S (‰) | $\sigma_T$ (gm/L) | $\delta_T$ (cl/T) | $\delta$ (cl/T) | $\Delta D_{Z/0}$ (dyn m) | $\Delta D_{Z/Z\,MAX}$ (dyn m) | $Q_Z$ (m-dynm) |
| 0 | 16.08 | 19.02 | 34.36 | 25.26 | 272.2 | 272.3 | 0 | 1.054 | 299.3 |
| 10 | 15.95 | 19.03 | 34.37 | 25.29 | 268.7 | 269.1 | .027 | 1.027 | 288.9 |
| 20 | 15.72 | 19.04 | 34.39 | 25.36 | 262.4 | 263.1 | .054 | 1.001 | 278.7 |
| 30 | 15.52 | 19.04 | 34.40 | 25.41 | 257.5 | 258.6 | .080 | .975 | 268.8 |
| 50 | 15.20 | 19.05 | 34.41 | 25.49 | 249.5 | 251.1 | .131 | .924 | 249.9 |
| 75 | 14.67 | 19.11 | 34.53 | 25.70 | 230.1 | 232.4 | .191 | .863 | 227.5 |
| 100 | 14.01 | 19.08 | 34.47 | 25.79 | 221.4 | 224.3 | .248 | .806 | 206.7 |
| 150 | 12.69 | 19.00 | 34.32 | 25.95 | 206.5 | 210.6 | .357 | .697 | 169.1 |
| 200 | 11.20 | 18.99 | 34.31 | 26.22 | 180.6 | 185.5 | .456 | .598 | 136.7 |
| 250 | 9.50 | 19.00 | 34.33 | 26.53 | 151.2 | 156.6 | .542 | .513 | 108.9 |
| 300 | 8.17 | 19.02 | 34.36 | 26.77 | 128.6 | 134.3 | .614 | .440 | 85.1 |
| 400 | 6.62 | 19.04 | 34.40 | 27.02 | 104.9 | 111.2 | .737 | .317 | 47.2 |
| 500 | 6.12 | 19.04 | 34.40 | 27.09 | 98.3 | 105.6 | .845 | .209 | 20.9 |
| 600 | 5.71 | 19.02 | 34.37 | 27.11 | 96.3 | 104.5 | .950 | .104 | 5.2 |
| 700 | 5.37 | 19.01 | 34.34 | 27.13 | 94.6 | 103.6 | 1.054 | 0 | 0 |

| STATION | DATE | TIME | LATITUDE | LONGITUDE | D |
|---|---|---|---|---|---|
| H 088 | NOV 17, 1963 | 0545- | 34° 38.0'S | 101° 33.0'W | 33 |

OBSERVED AND COMPUTED VALUES AT OBSERVED DEPTHS

| Z (m) | T (°C) | Cl (‰) | S (‰) | $O_2$ (ml/L) | $\sigma_T$ (gm/L) | $\delta_T$ (cl/L) | AOU (ml/L) | $PO_4$ (µg at./L) | $NO_3$ (µg at./L) | $SiO_4$ (µg at./L) | $NO_2$ (µg at./L) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 0 | 15.40 | 19.05 | 34.42 | 5.77 | 25.45 | 253.7 | -.28 | .21 | 2.5 | .3 | .11 |
| 25 | 15.25 | 19.01 | 34.34 | 6.00 | 25.43 | 255.8 | -.49 | .21 | 1.7 | .2 | .04 |
| 50 | 14.91 | 19.01 | 34.34 | 5.82 | 25.50 | 248.7 | -.28 | .20 | 1.3 | .1 | .04 |
| 75 | 13.57 | 19.02 | 34.36 | 6.08 | 25.80 | 220.4 | -.39 | -0 | -0 | -0 | -0 |
| 100 | 13.02 | 18.99 | 34.31 | 6.04 | 25.87 | 213.8 | -.28 | .26 | 3.1 | .2 | .10 |
| 150 | 11.58 | 18.96 | 34.25 | 5.96 | 26.11 | 191.4 | -.02 | .40 | 7.7 | .4 | .43 |
| 218 | 10.27 | 19.04 | 34.40 | 5.28 | 26.45 | 158.4 | .83 | .60 | 15.3 | 1.3 | .04 |
| 314 | 7.56 | 19.05 | 34.42 | 5.17 | 26.90 | 116.2 | 1.33 | 1.08 | 23.4 | 4.8 | .01 |
| 409 | 6.60 | 19.04 | 34.40 | 5.25 | 27.02 | 104.8 | 1.40 | 1.27 | 25.6 | 7.5 | .01 |
| 606 | 5.69 | 19.02 | 34.36 | 5.73 | 27.11 | 96.4 | 1.08 | 1.04 | 26.2 | 9.3 | .02 |

INTERPOLATED AND COMPUTED VALUES AT STANDARD DEPTHS

| Z (m) | T (°C) | Cl (‰) | S (‰) | $\sigma_T$ (gm/L) | $\delta_T$ (cl/T) | $\delta$ (cl/T) | $\Delta D_{Z/0}$ (dyn m) | $\Delta D_{Z/Z MAX}$ (dyn m) | $Q_Z$ (m-dyn m) |
|---|---|---|---|---|---|---|---|---|---|
| 0 | 15.40 | 19.05 | 34.41 | 25.45 | 253.7 | 253.8 | 0 | .920 | 227.1 |
| 10 | 15.36 | 19.03 | 34.38 | 25.43 | 255.2 | 255.6 | .025 | .894 | 218.1 |
| 20 | 15.30 | 19.02 | 34.36 | 25.43 | 255.6 | 256.4 | .051 | .869 | 209.3 |
| 30 | 15.20 | 19.01 | 34.34 | 25.44 | 254.8 | 255.8 | .077 | .843 | 200.7 |
| 50 | 14.91 | 19.01 | 34.34 | 25.50 | 248.7 | 250.3 | .127 | .793 | 184.3 |
| 75 | 13.57 | 19.02 | 34.36 | 25.80 | 220.4 | 222.6 | .186 | .733 | 165.3 |
| 100 | 13.02 | 18.99 | 34.31 | 25.87 | 213.8 | 216.6 | .241 | .679 | 147.6 |
| 150 | 11.58 | 18.96 | 34.25 | 26.11 | 191.4 | 195.2 | .344 | .576 | 116.3 |
| 200 | 10.57 | 19.02 | 34.36 | 26.37 | 166.0 | 170.7 | .436 | .484 | 89.8 |
| 250 | 9.25 | 19.04 | 34.39 | 26.62 | 142.5 | 147.8 | .515 | .404 | 67.6 |
| 300 | 7.90 | 19.05 | 34.41 | 26.84 | 121.4 | 127.0 | .584 | .336 | 49.0 |
| 400 | 6.68 | 19.04 | 34.40 | 27.01 | 105.8 | 112.1 | .704 | .216 | 21.4 |
| 500 | 6.14 | 19.03 | 34.38 | 27.06 | 100.5 | 107.8 | .814 | .106 | 5.3 |
| 600 | 5.71 | 19.02 | 34.36 | 27.10 | 96.6 | 104.8 | .920 | 0 | 0 |

H 088

| STATION | DATE | TIME | LATITUDE | LONGITUDE | D |
|---|---|---|---|---|---|
| H 091 | NOV 18, 1963 | 1200- | 34° 05.0'S | 096° 27.0'W | 27 |

OBSERVED AND COMPUTED VALUES AT OBSERVED DEPTHS

| Z (m) | T (°C) | Cl (‰) | S (‰) | $O_2$ (ml/L) | $\sigma_T$ (gm/L) | $\delta_T$ (cl/L) | AOU (ml/L) | $PO_4$ (µg at./L) | $NO_3$ (µg at./L) | $SiO_4$ (µg at./L) | $NO_2$ (µg at./L) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 0 | 16.18 | 18.98 | 34.29 | 5.89 | 25.18 | 279.6 | -.48 | .26 | 1.9 | .3 | .07 |
| 25 | 15.21 | 18.94 | 34.22 | 6.04 | 25.34 | 264.2 | -.53 | .19 | 1.8 | .2 | .04 |
| 50 | 14.48 | 18.96 | 34.25 | 6.03 | 25.53 | 246.5 | -.44 | .19 | 1.7 | .2 | .05 |
| 74 | 13.50 | 18.98 | 34.29 | 6.02 | 25.76 | 224.4 | -.31 | .22 | 2.2 | .2 | .09 |
| 98 | 13.18 | 18.96 | 34.25 | 5.87 | 25.80 | 220.8 | -.13 | .28 | 3.3 | .2 | .16 |
| 147 | 11.82 | 18.86 | 34.07 | 5.96 | 25.92 | 208.9 | -.04 | .38 | 7.2 | .3 | .24 |
| 214 | 11.07 | 18.91 | 34.16 | 5.41 | 26.13 | 189.2 | .60 | .57 | 12.5 | .8 | .05 |
| 308 | 7.99 | 18.93 | 34.20 | 5.20 | 26.67 | 138.3 | 1.25 | 1.07 | 22.7 | 3.9 | .02 |
| 408 | 6.66 | 19.06 | 34.43 | 5.23 | 27.04 | 102.9 | 1.41 | 1.22 | 26.9 | 7.6 | .01 |
| 614 | 5.58 | 18.94 | 34.22 | 5.59 | 27.01 | 105.9 | 1.24 | 1.62 | 28.4 | -0 | .03 |

H 091

INTERPOLATED AND COMPUTED VALUES AT STANDARD DEPTHS

| Z (m) | T (°C) | Cl (‰) | S (‰) | $\sigma_T$ (gm/L) | $\delta_T$ (cl/T) | $\delta$ (cl/T) | $\Delta D_{Z/0}$ (dyn m) | $\Delta D_{Z/Z MAX}$ (dyn m) | $Q_Z$ (m-dyn m) |
|---|---|---|---|---|---|---|---|---|---|
| 0 | 16.18 | 18.98 | 34.29 | 25.18 | 279.6 | 279.8 | 0 | .986 | 243.9 |
| 10 | 15.94 | 18.97 | 34.27 | 25.22 | 275.8 | 276.2 | .028 | .958 | 234.2 |
| 20 | 15.53 | 18.95 | 34.24 | 25.29 | 269.3 | 270.1 | .055 | .931 | 224.8 |
| 30 | 15.09 | 18.94 | 34.22 | 25.37 | 261.4 | 262.4 | .082 | .904 | 215.6 |
| 50 | 14.48 | 18.96 | 34.25 | 25.53 | 246.5 | 248.0 | .133 | .853 | 198.0 |
| 75 | 13.48 | 18.98 | 34.29 | 25.76 | 224.2 | 226.4 | .192 | .794 | 177.4 |
| 100 | 13.11 | 18.95 | 34.24 | 25.80 | 220.2 | 223.0 | .248 | .738 | 158.3 |
| 150 | 11.78 | 18.86 | 34.08 | 25.93 | 207.9 | 211.7 | .357 | .629 | 124.1 |
| 200 | 11.21 | 18.90 | 34.15 | 26.09 | 192.7 | 197.6 | .459 | .527 | 95.2 |
| 250 | 9.76 | 18.91 | 34.16 | 26.36 | 167.4 | 172.9 | .552 | .434 | 71.1 |
| 300 | 8.21 | 18.93 | 34.19 | 26.63 | 141.9 | 147.6 | .632 | .354 | 51.4 |
| 400 | 6.75 | 19.05 | 34.42 | 27.01 | 105.4 | 111.8 | .762 | .224 | 22.5 |
| 500 | 6.12 | 19.00 | 34.32 | 27.02 | 104.4 | 111.7 | .873 | .113 | 5.6 |
| 600 | 5.64 | 18.95 | 34.23 | 27.01 | 105.8 | 113.8 | .986 | 0 | 0 |

| STATION | DATE | TIME | LATITUDE | LONGITUDE | D |
|---|---|---|---|---|---|
| H 093 | NOV 19, 1963 | 0610- | 33° 59.0'S | 094° 08.0'W | 31 |

OBSERVED AND COMPUTED VALUES AT OBSERVED DEPTHS

| Z (m) | T (°C) | Cl (‰) | S (‰) | $O_2$ (ml/L) | $\sigma_T$ (gm/L) | $\delta_T$ (cl/L) | AOU (ml/L) | $PO_4$ | $NO_3$ | $SiO_4$ | $NO_2$ |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | —— (μg at./L) —— | | | |
| 0 | 15.80 | 18.95 | 34.23 | 5.66 | 25.22 | 275.4 | -.21 | .23 | 3.0 | 1.1 | -0 |
| 25 | 15.43 | 18.92 | 34.18 | 5.56 | 25.27 | 271.4 | -.07 | .19 | 1.6 | .9 | .04 |
| 50 | 14.20 | 18.99 | 34.31 | 5.89 | 25.63 | 236.9 | -.27 | .20 | 1.4 | 1.0 | .05 |
| 75 | 14.15 | 19.07 | 34.45 | 5.65 | 25.75 | 225.3 | -.03 | .20 | 1.3 | .7 | .06 |
| 100 | 14.01 | 19.06 | 34.43 | 5.58 | 25.77 | 223.8 | .06 | .21 | 1.8 | .8 | .08 |
| 150 | 13.10 | 18.93 | 34.20 | 5.52 | 25.77 | 223.3 | .24 | .27 | 4.7 | 1.1 | .20 |
| 223 | 11.14 | 18.92 | 34.18 | 5.05 | 26.13 | 189.0 | .95 | .56 | 12.1 | 1.4 | .04 |
| 322 | 8.30 | 18.95 | 34.23 | 4.71 | 26.65 | 140.0 | 1.69 | .72 | -0 | 1.7 | -0 |
| 410 | 6.67 | 18.97 | 34.27 | 4.82 | 26.91 | 115.1 | 1.83 | 1.25 | 27.3 | 9.0 | .01 |
| 625 | 5.57 | 18.94 | 34.22 | 5.45 | 27.01 | 105.8 | 1.38 | 1.20 | 27.9 | 10.9 | .01 |

INTERPOLATED AND COMPUTED VALUES AT STANDARD DEPTHS

| Z (m) | T (°C) | Cl (‰) | S (‰) | $\sigma_T$ (gm/L) | $\delta_T$ (cl/T) | $\delta$ (cl/T) | $\Delta D_{Z/0}$ (dyn m) | $\Delta D_{Z/Z\,MAX}$ (dyn m) | $Q_Z$ (m-dynm) |
|---|---|---|---|---|---|---|---|---|---|
| 0 | 15.80 | 18.95 | 34.23 | 25.22 | 275.4 | 275.5 | 0 | 1.026 | 256.9 |
| 10 | 15.71 | 18.94 | 34.22 | 25.23 | 274.4 | 274.8 | .028 | .998 | 246.8 |
| 20 | 15.55 | 18.93 | 34.20 | 25.25 | 272.8 | 273.5 | .055 | .971 | 237.0 |
| 30 | 15.24 | 18.93 | 34.19 | 25.32 | 266.5 | 267.6 | .082 | .944 | 227.4 |
| 50 | 14.20 | 18.99 | 34.31 | 25.63 | 236.9 | 238.4 | .133 | .893 | 209.0 |
| 75 | 14.15 | 19.07 | 34.45 | 25.75 | 225.3 | 227.5 | .191 | .835 | 187.4 |
| 100 | 14.01 | 19.06 | 34.43 | 25.76 | 223.8 | 226.7 | .248 | .778 | 167.3 |
| 150 | 13.10 | 18.93 | 34.20 | 25.77 | 223.3 | 227.4 | .361 | .665 | 131.2 |
| 200 | 11.68 | 18.92 | 34.18 | 26.03 | 198.4 | 203.5 | .469 | .557 | 100.7 |
| 250 | 10.26 | 18.92 | 34.19 | 26.29 | 173.8 | 179.5 | .565 | .461 | 75.2 |
| 300 | 8.85 | 18.94 | 34.22 | 26.55 | 149.4 | 155.5 | .648 | .377 | 54.3 |
| 400 | 6.84 | 18.97 | 34.26 | 26.88 | 117.7 | 124.1 | .788 | .238 | 23.5 |
| 500 | 6.15 | 18.95 | 34.24 | 26.96 | 110.8 | 118.1 | .909 | .116 | 5.8 |
| 600 | 5.68 | 18.94 | 34.22 | 27.00 | 106.7 | 114.8 | 1.026 | 0 | 0 |

| STATION | DATE | TIME | LATITUDE | LONGITUDE | D |
|---|---|---|---|---|---|
| H 095 | NOV 20, 1963 | 0830-0909 | 32° 59.0'S | 090° 19.0'W | 38 |

OBSERVED AND COMPUTED VALUES AT OBSERVED DEPTHS

| Z (m) | T (°C) | Cl (‰) | S (‰) | $O_2$ (ml/L) | $\sigma_T$ (gm/L) | $\delta_T$ (cl/L) | AOU (ml/L) | $PO_4$ | $NO_3$ | $SiO_4$ | $NO_2$ |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | —— (μg at./L) —— | | | |
| 0 | 16.70 | 19.03 | 34.38 | 5.50 | 25.13 | 284.5 | -.15 | .24 | 1.8 | 1.0 | .06 |
| 25 | 16.09 | 19.00 | 34.33 | 5.51 | 25.23 | 275.0 | -.09 | .22 | 1.2 | .9 | .03 |
| 50 | 14.55 | 18.99 | 34.31 | 5.81 | 25.55 | 243.9 | -.23 | .21 | 1.1 | 1.0 | .05 |
| 75 | 14.17 | 19.03 | 34.38 | 5.67 | 25.69 | 231.0 | -.05 | .23 | 1.6 | .8 | .08 |
| 100 | 13.64 | 18.99 | 34.31 | 5.57 | 25.75 | 225.8 | .12 | .29 | 2.8 | .8 | .15 |
| 150 | 12.75 | 18.93 | 34.20 | 5.46 | 25.84 | 216.7 | .34 | .34 | 5.3 | 1.0 | .37 |
| 200 | 11.38 | 18.90 | 34.14 | 5.00 | 26.06 | 195.8 | .97 | .62 | 13.2 | 1.6 | .04 |
| 295 | 8.28 | 18.93 | 34.20 | 4.37 | 26.62 | 142.4 | 2.03 | 1.08 | 24.6 | 6.9 | .01 |
| 389 | 6.68 | 18.97 | 34.27 | 4.39 | 26.91 | 115.3 | 2.26 | 1.29 | 28.8 | 11.2 | .01 |
| 573 | 5.51 | 18.95 | 34.23 | 5.19 | 27.03 | 103.8 | 1.65 | 1.23 | 29.7 | 12.4 | .02 |

INTERPOLATED AND COMPUTED VALUES AT STANDARD DEPTHS

| Z (m) | T (°C) | Cl (‰) | S (‰) | $\sigma_T$ (gm/L) | $\delta_T$ (cl/T) | $\delta$ (cl/T) | $\Delta D_{Z/0}$ (dyn m) | $\Delta D_{Z/Z\,MAX}$ (dyn m) | $Q_Z$ (m-dynm) |
|---|---|---|---|---|---|---|---|---|---|
| 0 | 16.70 | 19.03 | 34.38 | 25.13 | 284.5 | 284.6 | 0 | 1.007 | 248.9 |
| 10 | 16.55 | 19.02 | 34.36 | 25.15 | 282.1 | 282.6 | .028 | .978 | 239.0 |
| 20 | 16.29 | 19.01 | 34.34 | 25.19 | 278.2 | 279.0 | .056 | .950 | 229.3 |
| 30 | 15.84 | 19.00 | 34.32 | 25.28 | 270.1 | 271.2 | .084 | .923 | 220.0 |
| 50 | 14.55 | 18.99 | 34.31 | 25.55 | 243.9 | 245.5 | .136 | .871 | 202.0 |
| 75 | 14.17 | 19.03 | 34.38 | 25.69 | 231.0 | 233.2 | .195 | .811 | 181.0 |
| 100 | 13.64 | 18.99 | 34.31 | 25.74 | 225.8 | 228.6 | .253 | .754 | 161.4 |
| 150 | 12.75 | 18.93 | 34.20 | 25.84 | 216.7 | 220.7 | .366 | .641 | 126.6 |
| 200 | 11.38 | 18.90 | 34.14 | 26.06 | 195.8 | 200.8 | .471 | .536 | 97.1 |
| 250 | 9.60 | 18.91 | 34.16 | 26.38 | 165.2 | 170.6 | .564 | .443 | 72.6 |
| 300 | 8.18 | 18.93 | 34.20 | 26.64 | 140.7 | 146.4 | .643 | .364 | 52.5 |
| 400 | 6.60 | 18.97 | 34.27 | 26.92 | 114.4 | 120.7 | .777 | .230 | 22.8 |
| 500 | 5.92 | 18.96 | 34.24 | 26.99 | 107.8 | 114.9 | .894 | .113 | 5.6 |
| 600 | 5.37 | 18.95 | 34.23 | 27.04 | 102.4 | 110.1 | 1.007 | 0 | 0 |

H 096

| STATION | DATE | TIME | LATITUDE | LONGITUDE | D |
|---|---|---|---|---|---|
| H 096 | NOV 20, 1963 | 2015–2100 | 32° 23.0'S | 087° 51.0'W | |

OBSERVED AND COMPUTED VALUES AT OBSERVED DEPTHS

| Z (m) | T (°C) | Cl (‰) | S (‰) | $O_2$ (ml/L) | $\sigma_T$ (gm/L) | $\delta_T$ (cl/L) | AOU (ml/L) | $PO_4$ (µg at./L) | $NO_3$ (µg at./L) | $SiO_4$ (µg at./L) | $NO_2$ (µg at./L) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 0 | 17.10 | 19.18 | 34.65 | 5.45 | 25.24 | 273.8 | −.15 | .21 | 1.4 | .8 | .06 |
| 25 | 16.50 | 19.13 | 34.56 | 5.63 | 25.31 | 266.9 | −.26 | .14 | .2 | .9 | .02 |
| 50 | 15.78 | 19.12 | 34.54 | 5.55 | 25.46 | 252.5 | −.11 | −0 | −0 | −0 | −0 |
| 75 | 15.48 | 19.16 | 34.61 | 5.54 | 25.59 | 240.9 | −.07 | .17 | .5 | .9 | .04 |
| 100 | 14.98 | 19.15 | 34.60 | 5.38 | 25.68 | 231.7 | .15 | .19 | 1.2 | .8 | .10 |
| 150 | 15.18 | 19.19 | 34.67 | 5.36 | 25.70 | 230.6 | .14 | .18 | 1.8 | .6 | .10 |
| 199 | 13.92 | 19.07 | 34.45 | 5.12 | 25.80 | 220.7 | .53 | .32 | 4.8 | .6 | .20 |
| 292 | 9.19 | 18.97 | 34.27 | 4.46 | 26.54 | 150.6 | 1.81 | .97 | 22.0 | 4.9 | .01 |
| 391 | 7.05 | 18.99 | 34.31 | 3.81 | 26.89 | 117.4 | 2.78 | 1.51 | 30.5 | 14.0 | .01 |
| 565 | 5.52 | 18.97 | 34.27 | 5.12 | 27.06 | 101.2 | 1.72 | 1.60 | 29.1 | 12.7 | .01 |

INTERPOLATED AND COMPUTED VALUES AT STANDARD DEPTHS

| Z (m) | T (°C) | Cl (‰) | S (‰) | $\sigma_T$ (gm/L) | $\delta_T$ (cl/T) | $\delta$ (cl/T) | $\Delta D_{Z/0}$ (dyn m) | $\Delta D_{Z/Z\,MAX}$ (dyn m) | $Q_Z$ (m-dyn m) |
|---|---|---|---|---|---|---|---|---|---|
| 0 | 17.10 | 19.18 | 34.65 | 25.24 | 273.8 | 273.9 | 0 | 1.043 | 256.1 |
| 10 | 16.95 | 19.17 | 34.63 | 25.26 | 272.1 | 272.5 | .027 | 1.016 | 245.8 |
| 20 | 16.70 | 19.15 | 34.59 | 25.29 | 269.2 | 270.0 | .054 | .989 | 235.8 |
| 30 | 16.39 | 19.13 | 34.55 | 25.33 | 264.9 | 265.9 | .081 | .962 | 226.1 |
| 50 | 15.78 | 19.12 | 34.54 | 25.46 | 252.5 | 254.2 | .133 | .910 | 207.3 |
| 75 | 15.48 | 19.16 | 34.61 | 25.59 | 240.9 | 243.2 | .195 | .848 | 185.4 |
| 100 | 14.98 | 19.15 | 34.60 | 25.68 | 231.7 | 234.7 | .255 | .788 | 164.9 |
| 150 | 15.18 | 19.19 | 34.67 | 25.69 | 230.6 | 235.1 | .373 | .671 | 128.5 |
| 200 | 13.88 | 19.07 | 34.45 | 25.80 | 220.1 | 225.8 | .488 | .555 | 97.8 |
| 250 | 11.31 | 18.99 | 34.32 | 26.21 | 182.0 | 188.1 | .591 | .452 | 72.6 |
| 300 | 8.99 | 18.97 | 34.27 | 26.57 | 147.5 | 153.6 | .677 | .367 | 52.1 |
| 400 | 6.96 | 18.99 | 34.30 | 26.90 | 116.4 | 122.9 | .815 | .228 | 22.4 |
| 500 | 6.03 | 18.97 | 34.28 | 27.00 | 106.6 | 113.7 | .933 | .110 | 5.5 |
| 600 | 5.27 | 18.97 | 34.27 | 27.08 | 98.6 | 106.2 | 1.043 | 0 | 0 |

H 097

| STATION | DATE | TIME | LATITUDE | LONGITUDE | D |
|---|---|---|---|---|---|
| H 097 | NOV 21, 1963 | 0600–0640 | 32° 22.0'S | 086° 40.0'W | 31 |

OBSERVED AND COMPUTED VALUES AT OBSERVED DEPTHS

| Z (m) | T (°C) | Cl (‰) | S (‰) | $O_2$ (ml/L) | $\sigma_T$ (gm/L) | $\delta_T$ (cl/L) | AOU (ml/L) | $PO_4$ (µg at./L) | $NO_3$ (µg at./L) | $SiO_4$ (µg at./L) | $NO_2$ (µg at./L) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 0 | 16.50 | 19.05 | 34.42 | 5.53 | 25.20 | 277.4 | −.16 | .34 | 1.2 | .4 | .08 |
| 25 | 16.12 | 19.06 | 34.43 | 5.52 | 25.30 | 267.8 | −.11 | .19 | .5 | .2 | .03 |
| 50 | 15.38 | 19.04 | 34.40 | 5.64 | 25.44 | 254.6 | −.15 | .22 | .4 | .3 | .03 |
| 75 | 14.70 | 19.03 | 34.38 | 5.63 | 25.58 | 241.7 | −.07 | .20 | .9 | .3 | .05 |
| 100 | 14.52 | 19.05 | 34.42 | 5.53 | 25.64 | 235.4 | .05 | .21 | 1.6 | .4 | .11 |
| 149 | 14.03 | 19.03 | 34.38 | 5.43 | 25.72 | 228.2 | .21 | .26 | 2.8 | .4 | .25 |
| 221 | 11.18 | 18.89 | 34.13 | 4.80 | 26.08 | 193.7 | 1.20 | .94 | 16.0 | 1.4 | .02 |
| 316 | 8.34 | 18.97 | 34.27 | 3.78 | 26.67 | 137.9 | 2.61 | 1.27 | 27.1 | 9.6 | .01 |
| 416 | 6.82 | 18.99 | 34.31 | 3.53 | 26.92 | 114.4 | 3.09 | 1.79 | 32.9 | 15.0 | .01 |
| 592 | 5.34 | 18.96 | 34.25 | 5.10 | 27.07 | 100.5 | 1.77 | 1.43 | 30.1 | 13.5 | .01 |

INTERPOLATED AND COMPUTED VALUES AT STANDARD DEPTHS

| Z (m) | T (°C) | Cl (‰) | S (‰) | $\sigma_T$ (gm/L) | $\delta_T$ (cl/T) | $\delta$ (cl/T) | $\Delta D_{Z/0}$ (dyn m) | $\Delta D_{Z/Z\,MAX}$ (dyn m) | $Q_Z$ (m-dyn m) |
|---|---|---|---|---|---|---|---|---|---|
| 0 | 16.50 | 19.05 | 34.41 | 25.20 | 277.4 | 277.6 | 0 | 1.034 | 254.3 |
| 10 | 16.41 | 19.05 | 34.42 | 25.23 | 275.0 | 275.5 | .028 | 1.006 | 244.1 |
| 20 | 16.25 | 19.06 | 34.43 | 25.27 | 271.0 | 271.8 | .055 | .978 | 234.1 |
| 30 | 16.01 | 19.06 | 34.43 | 25.32 | 265.8 | 266.8 | .082 | .952 | 224.5 |
| 50 | 15.38 | 19.04 | 34.40 | 25.44 | 254.6 | 256.2 | .134 | .899 | 206.0 |
| 75 | 14.70 | 19.03 | 34.38 | 25.58 | 241.7 | 244.0 | .197 | .837 | 184.3 |
| 100 | 14.52 | 19.05 | 34.41 | 25.64 | 235.4 | 238.4 | .257 | .776 | 164.1 |
| 150 | 14.00 | 19.03 | 34.38 | 25.72 | 227.7 | 232.1 | .375 | .659 | 128.2 |
| 200 | 11.98 | 18.92 | 34.19 | 25.98 | 203.4 | 208.5 | .485 | .549 | 98.1 |
| 250 | 10.20 | 18.91 | 34.16 | 26.28 | 174.5 | 180.1 | .582 | .451 | 73.0 |
| 300 | 8.75 | 18.95 | 34.24 | 26.58 | 146.0 | 152.0 | .665 | .368 | 52.5 |
| 400 | 7.04 | 18.99 | 34.30 | 26.88 | 117.7 | 124.3 | .803 | .230 | 22.6 |
| 500 | 6.05 | 18.97 | 34.27 | 26.99 | 107.1 | 114.3 | .923 | .111 | 5.5 |
| 600 | 5.28 | 18.96 | 34.25 | 27.07 | 100.0 | 107.6 | 1.034 | 0 | 0 |

| STATION | DATE | TIME | LATITUDE | LONGITUDE | D |
|---|---|---|---|---|---|
| H 098 | NOV 22, 1963 | 2015-2100 | 32° 16.0'S | 085° 44.0'W | |

OBSERVED AND COMPUTED VALUES AT OBSERVED DEPTHS

| Z | T | Cl | S | $O_2$ | $\sigma_T$ | $\delta_T$ | AOU | $PO_4$ | $NO_3$ | $SiO_4$ | $NO_2$ |
|---|---|---|---|---|---|---|---|---|---|---|---|
| (m) | (°C) | (‰) | (‰) | (ml/L) | (gm/L) | (cl/L) | (ml/L) | —— (µg at./L) —— | | | |
| 0 | 16.80 | 19.13 | 34.56 | 5.42 | 25.24 | 273.6 | -.09 | .20 | 1.5 | .5 | .08 |
| 24 | 16.64 | 19.17 | 34.63 | 5.47 | 25.34 | 264.8 | -.12 | .19 | .4 | .2 | .05 |
| 48 | 15.11 | 19.06 | 34.43 | 5.64 | 25.53 | 246.2 | -.12 | .20 | .5 | .4 | .03 |
| 72 | 15.03 | 19.17 | 34.63 | 5.42 | 25.70 | 230.1 | .10 | -0 | 1.5 | .3 | .11 |
| 96 | 14.41 | 19.08 | 34.47 | 5.79 | 25.71 | 229.2 | -.20 | -0 | 1.5 | .2 | .08 |
| 144 | 13.53 | 19.03 | 34.38 | 5.37 | 25.82 | 218.3 | .33 | .36 | 5.1 | .5 | .50 |
| 258 | 9.38 | 18.98 | 34.29 | 3.91 | 26.52 | 152.2 | 2.33 | 1.05 | 24.3 | 7.3 | .01 |
| 358 | 7.68 | 19.00 | 34.33 | 2.71 | 26.81 | 124.5 | 3.78 | 1.59 | 34.1 | 16.7 | .01 |
| 443 | 6.31 | 18.97 | 34.27 | 4.58 | 26.96 | 110.6 | 2.13 | 1.42 | 30.6 | 11.7 | 0 |
| 629 | 5.12 | 18.94 | 34.22 | 4.91 | 27.06 | 100.7 | 2.00 | 1.40 | 31.6 | 15.6 | .01 |

INTERPOLATED AND COMPUTED VALUES AT STANDARD DEPTHS

| Z | T | Cl | S | $\sigma_T$ | $\delta_T$ | $\delta$ | $\Delta D_{Z/0}$ | $\Delta D_{Z/Z\,MAX}$ | $Q_Z$ |
|---|---|---|---|---|---|---|---|---|---|
| (m) | (°C) | (‰) | (‰) | (gm/L) | (cl/T) | (cl/T) | (dyn m) | (dyn m) | (m-dyn m) |
| 0 | 16.80 | 19.13 | 34.56 | 25.24 | 273.6 | 273.7 | 0 | .992 | 246.6 |
| 10 | 16.76 | 19.14 | 34.58 | 25.27 | 271.3 | 271.7 | .027 | .964 | 236.8 |
| 20 | 16.69 | 19.16 | 34.61 | 25.31 | 267.3 | 268.0 | .054 | .937 | 227.3 |
| 30 | 16.36 | 19.15 | 34.60 | 25.38 | 260.8 | 261.9 | .081 | .911 | 218.1 |
| 50 | 15.10 | 19.07 | 34.45 | 25.55 | 244.6 | 246.2 | .132 | .860 | 200.4 |
| 75 | 14.94 | 19.16 | 34.61 | 25.70 | 229.9 | 232.3 | .191 | .800 | 179.6 |
| 100 | 14.32 | 19.07 | 34.46 | 25.72 | 228.1 | 231.1 | .249 | .742 | 160.3 |
| 150 | 13.24 | 19.02 | 34.37 | 25.87 | 213.7 | 217.9 | .362 | .630 | 126.0 |
| 200 | 11.19 | 18.99 | 34.30 | 26.21 | 181.1 | 186.0 | .462 | .529 | 97.1 |
| 250 | 9.60 | 18.98 | 34.29 | 26.48 | 155.7 | 161.1 | .549 | .442 | 72.8 |
| 300 | 8.60 | 18.99 | 34.30 | 26.65 | 139.4 | 145.3 | .626 | .366 | 52.6 |
| 400 | 6.97 | 18.98 | 34.29 | 26.89 | 117.3 | 123.8 | .760 | .231 | 22.7 |
| 500 | 5.90 | 18.96 | 34.25 | 26.99 | 107.2 | 114.3 | .880 | .112 | 5.6 |
| 600 | 5.28 | 18.94 | 34.22 | 27.05 | 102.1 | 109.7 | .992 | 0 | 0 |

| STATION | DATE | TIME | LATITUDE | LONGITUDE | D |
|---|---|---|---|---|---|
| H 099 | NOV 22, 1963 | 0830-0915 | 32° 43.0'S | 083° 19.0'W | 20 |

OBSERVED AND COMPUTED VALUES AT OBSERVED DEPTHS

| Z | T | Cl | S | $O_2$ | $\sigma_T$ | $\delta_T$ | AOU | $PO_4$ | $NO_3$ | $SiO_4$ | $NO_2$ |
|---|---|---|---|---|---|---|---|---|---|---|---|
| (m) | (°C) | (‰) | (‰) | (ml/L) | (gm/L) | (cl/L) | (ml/L) | —— (µg at./L) —— | | | |
| 0 | 16.50 | 19.07 | 34.45 | 5.48 | 25.23 | 274.8 | -.11 | .25 | .9 | .4 | .08 |
| 25 | 16.24 | 19.09 | 34.49 | 5.56 | 25.32 | 266.5 | -.17 | .21 | .3 | .3 | .02 |
| 50 | 15.95 | 19.12 | 34.54 | 5.60 | 25.43 | 256.2 | -.18 | .21 | .3 | .3 | .02 |
| 75 | 15.48 | 19.16 | 34.61 | 5.54 | 25.59 | 240.9 | -.07 | .20 | .6 | .2 | .04 |
| 99 | 15.40 | 19.16 | 34.61 | 5.37 | 25.60 | 239.2 | .11 | .29 | 1.0 | .4 | .10 |
| 148 | 13.46 | 19.03 | 34.38 | 4.91 | 25.84 | 217.0 | .80 | .50 | 8.1 | .6 | .06 |
| 216 | 10.62 | 18.93 | 34.20 | 4.37 | 26.24 | 178.9 | 1.70 | 1.07 | 19.3 | 3.3 | .02 |
| 307 | 8.66 | 19.01 | 34.34 | 3.02 | 26.68 | 137.2 | 3.32 | 1.67 | 28.4 | 13.0 | .02 |
| 399 | 7.12 | 19.01 | 34.34 | 3.14 | 26.91 | 115.6 | 3.43 | 1.80 | 31.8 | 16.4 | .01 |
| 584 | 5.38 | 18.98 | 34.29 | 4.97 | 27.09 | 98.2 | 1.89 | 1.56 | 28.7 | 13.5 | .02 |

INTERPOLATED AND COMPUTED VALUES AT STANDARD DEPTHS

| Z | T | Cl | S | $\sigma_T$ | $\delta_T$ | $\delta$ | $\Delta D_{Z/0}$ | $\Delta D_{Z/Z\,MAX}$ | $Q_Z$ |
|---|---|---|---|---|---|---|---|---|---|
| (m) | (°C) | (‰) | (‰) | (gm/L) | (cl/T) | (cl/T) | (dyn m) | (dyn m) | (m-dynm) |
| 0 | 16.50 | 19.07 | 34.45 | 25.23 | 274.8 | 274.9 | 0 | 1.004 | 246.2 |
| 10 | 16.43 | 19.07 | 34.46 | 25.25 | 272.7 | 273.2 | .027 | .976 | 236.3 |
| 20 | 16.33 | 19.08 | 34.47 | 25.29 | 269.2 | 270.0 | .055 | .949 | 226.7 |
| 30 | 16.19 | 19.09 | 34.50 | 25.33 | 264.9 | 265.9 | .081 | .922 | 217.3 |
| 50 | 15.95 | 19.12 | 34.54 | 25.42 | 256.2 | 257.9 | .134 | .870 | 199.4 |
| 75 | 15.48 | 19.16 | 34.61 | 25.59 | 240.9 | 243.2 | .196 | .807 | 178.4 |
| 100 | 15.37 | 19.16 | 34.61 | 25.61 | 238.8 | 241.9 | .257 | .747 | 159.0 |
| 150 | 13.39 | 19.03 | 34.37 | 25.85 | 216.0 | 220.2 | .373 | .631 | 124.6 |
| 200 | 11.26 | 18.95 | 34.23 | 26.15 | 187.4 | 192.3 | .476 | .528 | 95.6 |
| 250 | 9.81 | 18.96 | 34.25 | 26.42 | 161.6 | 167.0 | .566 | .438 | 71.4 |
| 300 | 8.79 | 19.00 | 34.33 | 26.65 | 140.0 | 146.0 | .644 | .360 | 51.5 |
| 400 | 7.11 | 19.01 | 34.34 | 26.91 | 115.5 | 122.2 | .778 | .226 | 22.2 |
| 500 | 6.09 | 18.99 | 34.31 | 27.01 | 105.3 | 112.6 | .895 | .109 | 5.4 |
| 600 | 5.26 | 18.98 | 34.29 | 27.10 | 97.0 | 104.6 | 1.004 | 0 | 0 |

H 100

| STATION | DATE | TIME | LATITUDE | LONGITUDE | D |
|---|---|---|---|---|---|
| H 100 | NOV 22, 1963 | 2010-2055 | 33° 08.0'S | 081° 03.0'W | |

OBSERVED AND COMPUTED VALUES AT OBSERVED DEPTHS

| Z | T | Cl | S | $O_2$ | $\sigma_T$ | $\delta_T$ | AOU | $PO_4$ | $NO_3$ | $SiO_4$ | $NO_2$ |
|---|---|---|---|---|---|---|---|---|---|---|---|
| (m) | (°C) | (‰) | (‰) | (ml/L) | (gm/L) | (cl/L) | (ml/L) | (μg at./L) | | | |
| 0 | 16.30 | 18.83 | 34.02 | 5.55 | 24.94 | 302.0 | -.14 | .25 | 1.2 | .2 | .06 |
| 25 | 15.20 | 18.84 | 34.04 | 5.67 | 25.21 | 277.2 | -.15 | .24 | .1 | 0 | .02 |
| 49 | 13.89 | 18.86 | 34.07 | 5.69 | 25.51 | 247.9 | -.02 | .34 | 2.0 | .1 | .08 |
| 73 | 13.57 | 18.80 | 33.96 | 5.49 | 25.50 | 249.5 | .22 | .37 | 3.5 | .3 | .34 |
| 98 | 13.31 | 18.83 | 34.02 | 5.53 | 25.59 | 240.5 | .21 | .41 | 4.4 | .4 | .34 |
| 147 | 12.24 | 18.87 | 34.09 | 5.31 | 25.86 | 215.2 | .56 | .62 | 9.7 | .7 | .16 |
| 225 | 9.80 | 18.95 | 34.23 | 3.55 | 26.41 | 162.8 | 2.63 | 1.39 | 24.3 | 8.3 | .03 |
| 313 | 8.51 | 999.00 | 999.00 | 1.66 | 999.00 | 999.0 | 999.00 | 2.09 | 34.3 | 21.1 | .02 |
| 410 | 6.94 | 18.90 | 34.14 | 2.85 | 26.77 | 128.0 | 3.76 | 1.89 | 35.2 | 18.1 | .02 |
| 595 | 5.33 | 18.94 | 34.22 | 4.70 | 27.04 | 103.1 | 2.17 | 1.65 | 31.3 | 16.0 | .02 |

INTERPOLATED AND COMPUTED VALUES AT STANDARD DEPTHS

| Z (m) | T (°C) | Cl (‰) | S (‰) | $\sigma_T$ (gm/L) | $\delta_T$ (cl/T) | $\delta$ (cl/T) | $\Delta D_{Z/0}$ (dyn m) | $\Delta D_{Z/Z\,MAX}$ (dyn m) | $Q_Z$ (m-dynm) |
|---|---|---|---|---|---|---|---|---|---|
| 0 | 16.30 | 18.83 | 34.02 | 24.94 | 302.0 | 302.1 | 0 | 1.031 | 257.7 |
| 10 | 16.02 | 18.83 | 34.02 | 25.01 | 295.8 | 296.2 | .030 | 1.002 | 247.6 |
| 20 | 15.57 | 18.84 | 34.03 | 25.12 | 285.4 | 286.2 | .059 | .972 | 237.7 |
| 30 | 14.96 | 18.84 | 34.04 | 25.26 | 271.8 | 272.8 | .087 | .944 | 228.1 |
| 50 | 13.87 | 18.86 | 34.07 | 25.51 | 248.0 | 249.5 | .139 | .892 | 209.7 |
| 75 | 13.55 | 18.80 | 33.97 | 25.50 | 248.7 | 250.9 | .202 | .830 | 188.2 |
| 100 | 13.26 | 18.83 | 34.02 | 25.60 | 239.3 | 242.1 | .263 | .768 | 168.2 |
| 150 | 12.12 | 18.87 | 34.10 | 25.88 | 212.7 | 216.6 | .378 | .653 | 132.7 |
| 200 | 10.48 | 18.92 | 34.19 | 26.25 | 177.3 | 182.0 | .478 | .554 | 102.5 |
| 250 | 9.39 | 18.95 | 34.23 | 26.47 | 156.7 | 162.0 | .564 | .468 | 77.0 |
| 300 | 8.68 | 18.94 | 34.23 | 26.58 | 146.1 | 152.1 | .642 | .389 | 55.6 |
| 400 | 7.08 | 18.90 | 34.15 | 26.76 | 129.5 | 136.1 | .786 | .245 | 23.9 |
| 500 | 6.08 | 18.92 | 34.18 | 26.91 | 114.8 | 122.0 | .915 | .116 | 5.8 |
| 600 | 5.29 | 18.94 | 34.22 | 27.04 | 102.5 | 110.2 | 1.031 | 0 | 0 |

H 101

| STATION | DATE | TIME | LATITUDE | LONGITUDE | D |
|---|---|---|---|---|---|
| H 101 | NOV 23, 1963 | 0830-0900 | 33° 14.0'S | 078° 28.0'W | 20 |

OBSERVED AND COMPUTED VALUES AT OBSERVED DEPTHS

| Z | T | Cl | S | $O_2$ | $\sigma_T$ | $\delta_T$ | AOU | $PO_4$ | $NO_3$ | $SiO_4$ | $NO_2$ |
|---|---|---|---|---|---|---|---|---|---|---|---|
| (m) | (°C) | (‰) | (‰) | (ml/L) | (gm/L) | (cl/L) | (ml/L) | (μg at./L) | | | |
| 0 | 15.80 | 18.88 | 34.11 | 5.62 | 25.13 | 284.6 | -.16 | .43 | .4 | .2 | .06 |
| 25 | 15.40 | 18.85 | 34.05 | 5.67 | 25.17 | 280.0 | -.17 | .36 | .1 | 0 | .02 |
| 49 | 15.21 | 18.91 | 34.16 | 5.65 | 25.30 | 268.1 | -.13 | .30 | .1 | 0 | .02 |
| 73 | 13.07 | 18.93 | 34.20 | 5.43 | 25.78 | 222.7 | .33 | .47 | 4.5 | .6 | .42 |
| 98 | 12.76 | 18.93 | 34.20 | 5.38 | 25.84 | 216.8 | .42 | .51 | 6.9 | .6 | .16 |
| 147 | 10.44 | 18.87 | 34.09 | 4.38 | 26.19 | 183.9 | 1.72 | 1.08 | 20.5 | 3.6 | .03 |
| 208 | 9.39 | 18.95 | 34.23 | 2.48 | 26.48 | 156.3 | 3.76 | 1.68 | 28.6 | 14.1 | .02 |
| 304 | 8.42 | 19.05 | 34.42 | 1.32 | 26.77 | 128.3 | 5.05 | 2.16 | 35.7 | 23.1 | .02 |
| 391 | 6.94 | 19.01 | 34.34 | 2.83 | 26.93 | 113.2 | 3.77 | 2.01 | 34.9 | 18.9 | .02 |
| 580 | 5.23 | 18.98 | 34.29 | 4.68 | 27.11 | 96.6 | 2.21 | 1.55 | 31.7 | 16.7 | .02 |

INTERPOLATED AND COMPUTED VALUES AT STANDARD DEPTHS

| Z (m) | T (°C) | Cl (‰) | S (‰) | $\sigma_T$ (gm/L) | $\delta_T$ (cl/T) | $\delta$ (cl/T) | $\Delta D_{Z/0}$ (dyn m) | $\Delta D_{Z/Z\,MAX}$ (dyn m) | $Q_Z$ (m-dynm) |
|---|---|---|---|---|---|---|---|---|---|
| 0 | 15.80 | 18.88 | 34.11 | 25.13 | 284.6 | 284.7 | 0 | .941 | 231.3 |
| 10 | 15.70 | 18.87 | 34.09 | 25.14 | 283.5 | 283.9 | .028 | .912 | 222.0 |
| 20 | 15.53 | 18.86 | 34.07 | 25.16 | 281.6 | 282.3 | .057 | .884 | 213.0 |
| 30 | 15.37 | 18.86 | 34.07 | 25.19 | 278.3 | 279.4 | .085 | .856 | 204.3 |
| 50 | 15.15 | 18.91 | 34.16 | 25.31 | 266.8 | 268.4 | .140 | .801 | 187.8 |
| 75 | 13.04 | 18.93 | 34.20 | 25.78 | 222.2 | 224.3 | .201 | .740 | 168.5 |
| 100 | 12.64 | 18.93 | 34.19 | 25.86 | 215.2 | 217.9 | .256 | .684 | 150.7 |
| 150 | 10.38 | 18.87 | 34.10 | 26.20 | 182.3 | 185.8 | .357 | .583 | 119.0 |
| 200 | 9.51 | 18.94 | 34.22 | 26.44 | 159.5 | 163.8 | .445 | .496 | 92.0 |
| 250 | 8.92 | 19.00 | 34.32 | 26.62 | 142.8 | 147.9 | .523 | .418 | 69.2 |
| 300 | 8.45 | 19.05 | 34.41 | 26.76 | 129.3 | 135.1 | .593 | .347 | 50.0 |
| 400 | 6.84 | 19.01 | 34.34 | 26.94 | 112.3 | 118.7 | .720 | .220 | 21.6 |
| 500 | 5.87 | 18.99 | 34.30 | 27.04 | 102.8 | 109.9 | .835 | .106 | 5.3 |
| 600 | 5.08 | 18.98 | 34.29 | 27.12 | 95.1 | 102.5 | .941 | 0 | 0 |

| STATION | DATE | TIME | LATITUDE | LONGITUDE | D |
|---|---|---|---|---|---|
| H 102 | NOV 23, 1963 | 2010-2100 | 33° 18.0'S | 077° 55.0'W | |

OBSERVED AND COMPUTED VALUES AT OBSERVED DEPTHS

| Z (m) | T (°C) | Cl (‰) | S (‰) | $O_2$ (ml/L) | $\sigma_T$ (gm/L) | $\delta_T$ (cl/L) | AOU (ml/L) | $PO_4$ | $NO_3$ (µg at./L) | $SiO_4$ | $NO_2$ |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 0 | 16.60 | 18.77 | 33.91 | 5.49 | 24.79 | 316.5 | -.11 | .31 | .3 | .3 | .09 |
| 24 | 15.92 | 18.74 | 33.86 | 5.52 | 24.91 | 305.6 | -.07 | .29 | .1 | .2 | .02 |
| 48 | 14.91 | 18.75 | 33.87 | 5.47 | 25.14 | 283.0 | .09 | .26 | 3.5 | .3 | .05 |
| 72 | 13.00 | 18.76 | 33.89 | 5.54 | 25.55 | 243.9 | .24 | .51 | 4.9 | .7 | .31 |
| 96 | 12.16 | 18.78 | 33.93 | 4.72 | 25.75 | 225.7 | 1.16 | 1.13 | 14.4 | 2.5 | .05 |
| 144 | 10.44 | 18.89 | 34.13 | 2.89 | 26.21 | 181.2 | 3.21 | 1.67 | 26.4 | 10.3 | .03 |
| 224 | 10.06 | 19.12 | 34.54 | .85 | 26.60 | 144.3 | 5.28 | 2.50 | -0 | 21.3 | -0 |
| 312 | 8.41 | 19.05 | 34.42 | 1.19 | 26.77 | 128.2 | 5.18 | 2.31 | 36.8 | 24.2 | .02 |
| 408 | 6.97 | 19.00 | 34.33 | 2.38 | 26.91 | 115.0 | 4.22 | 2.04 | 36.5 | 22.1 | .02 |
| 599 | 5.26 | 18.95 | 34.23 | 4.05 | 27.06 | 101.0 | 2.83 | 1.91 | 34.9 | 21.3 | .02 |

INTERPOLATED AND COMPUTED VALUES AT STANDARD DEPTHS

| Z (m) | T (°C) | Cl (‰) | S (‰) | $\sigma_T$ (gm/L) | $\delta_T$ (cl/T) | $\delta$ (cl/T) | $\Delta D_{Z/0}$ (dyn m) | $\Delta D_{Z/Z\,MAX}$ (dyn m) | $Q_Z$ (m-dynm) |
|---|---|---|---|---|---|---|---|---|---|
| 0 | 16.60 | 18.77 | 33.91 | 24.79 | 316.5 | 316.6 | 0 | .967 | 236.8 |
| 10 | 16.42 | 18.76 | 33.89 | 24.82 | 313.6 | 314.1 | .032 | .936 | 227.3 |
| 20 | 16.11 | 18.75 | 33.87 | 24.87 | 308.7 | 309.5 | .063 | .905 | 218.1 |
| 30 | 15.73 | 18.74 | 33.86 | 24.95 | 301.5 | 302.6 | .093 | .874 | 209.2 |
| 50 | 14.78 | 18.75 | 33.87 | 25.17 | 280.3 | 281.9 | .152 | .816 | 192.3 |
| 75 | 12.88 | 18.76 | 33.90 | 25.58 | 241.3 | 243.4 | .217 | .750 | 172.7 |
| 100 | 11.99 | 18.79 | 33.95 | 25.79 | 221.2 | 223.9 | .276 | .692 | 154.7 |
| 150 | 10.40 | 18.91 | 34.16 | 26.25 | 177.8 | 181.3 | .377 | .590 | 122.7 |
| 200 | 10.16 | 19.06 | 34.43 | 26.50 | 153.8 | 158.3 | .462 | .505 | 95.3 |
| 250 | 9.51 | 19.09 | 34.50 | 26.66 | 138.9 | 144.3 | .538 | .430 | 71.9 |
| 300 | 8.61 | 19.06 | 34.43 | 26.75 | 130.1 | 136.0 | .608 | .360 | 52.2 |
| 400 | 7.08 | 19.00 | 34.33 | 26.90 | 116.0 | 122.6 | .737 | .230 | 22.7 |
| 500 | 6.06 | 18.97 | 34.27 | 26.99 | 107.6 | 114.8 | .856 | .112 | 5.6 |
| 600 | 5.25 | 18.95 | 34.23 | 27.06 | 100.9 | 108.5 | .967 | 0 | 0 |

| STATION | DATE | TIME | LATITUDE | LONGITUDE | D |
|---|---|---|---|---|---|
| H 103 | DEC 5, 1963 | 0830-0934 | 37° 05.8'S | 077° 55.2'W | 11 |

OBSERVED AND COMPUTED VALUES AT OBSERVED DEPTHS

| Z (m) | T (°C) | Cl (‰) | S (‰) | $O_2$ (ml/L) | $\sigma_T$ (gm/L) | $\delta_T$ (cl/L) | AOU (ml/L) | $PO_4$ | $NO_3$ (µg at./L) | $SiO_4$ | $NO_2$ |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 0 | 15.40 | 18.80 | 33.96 | 6.02 | 25.11 | 286.6 | -.52 | .36 | 1.3 | .5 | .15 |
| 24 | 15.17 | 18.81 | 33.98 | 6.16 | 25.17 | 280.5 | -.63 | .23 | .1 | .2 | .02 |
| 48 | 13.98 | 18.80 | 33.96 | 6.11 | 25.41 | 257.6 | -.45 | .33 | .6 | .2 | .05 |
| 71 | 12.36 | 18.78 | 33.93 | 5.96 | 25.71 | 229.3 | -.10 | .51 | 6.4 | .7 | .55 |
| 95 | 11.47 | 18.78 | 33.93 | 5.66 | 25.88 | 213.4 | .31 | .77 | 12.1 | 1.0 | .04 |
| 143 | 10.01 | 18.86 | 34.07 | 4.33 | 26.25 | 178.2 | 1.83 | 1.13 | 23.8 | 5.6 | .04 |
| 215 | 9.04 | 19.00 | 34.33 | 2.34 | 26.60 | 144.3 | 3.95 | 1.83 | 31.2 | 17.2 | .03 |
| 314 | 7.68 | 19.03 | 34.38 | 2.27 | 26.85 | 120.5 | 4.22 | 2.33 | 36.6 | 20.3 | .05 |
| 400 | 6.46 | 18.98 | 34.29 | 3.85 | 26.95 | 111.1 | 2.83 | 1.74 | 34.0 | 15.7 | .04 |
| 600 | 5.16 | 18.93 | 34.20 | 5.15 | 27.04 | 102.5 | 1.75 | 1.80 | 31.5 | 15.2 | .03 |

INTERPOLATED AND COMPUTED VALUES AT STANDARD DEPTHS

| Z (m) | T (°C) | Cl (‰) | S (‰) | $\sigma_T$ (gm/L) | $\delta_T$ (cl/T) | $\delta$ (cl/T) | $\Delta D_{Z/0}$ (dyn m) | $\Delta D_{Z/Z\,MAX}$ (dyn m) | $Q_Z$ (m-dynm) |
|---|---|---|---|---|---|---|---|---|---|
| 0 | 15.40 | 18.80 | 33.96 | 25.10 | 286.6 | 286.8 | 0 | .925 | 230.1 |
| 10 | 15.34 | 18.80 | 33.97 | 25.12 | 285.0 | 285.4 | .029 | .897 | 221.0 |
| 20 | 15.24 | 18.81 | 33.98 | 25.15 | 282.3 | 283.0 | .057 | .868 | 212.1 |
| 30 | 14.98 | 18.81 | 33.98 | 25.21 | 276.6 | 277.7 | .085 | .840 | 203.6 |
| 50 | 13.86 | 18.80 | 33.96 | 25.43 | 255.5 | 257.0 | .139 | .787 | 187.3 |
| 75 | 12.19 | 18.78 | 33.93 | 25.74 | 226.3 | 228.4 | .199 | .726 | 168.4 |
| 100 | 11.29 | 18.79 | 33.94 | 25.92 | 209.0 | 211.5 | .254 | .671 | 151.0 |
| 150 | 9.90 | 18.88 | 34.10 | 26.29 | 174.2 | 177.6 | .351 | .574 | 119.8 |
| 200 | 9.21 | 18.97 | 34.28 | 26.54 | 150.3 | 154.5 | .434 | .491 | 93.2 |
| 250 | 8.50 | 19.01 | 34.34 | 26.70 | 134.8 | 139.7 | .508 | .417 | 70.5 |
| 300 | 7.84 | 19.03 | 34.37 | 26.82 | 123.4 | 128.8 | .575 | .350 | 51.4 |
| 400 | 6.46 | 18.98 | 34.29 | 26.95 | 111.1 | 117.3 | .698 | .227 | 22.5 |
| 500 | 5.74 | 18.95 | 34.24 | 27.00 | 106.4 | 113.3 | .814 | .112 | 5.6 |
| 600 | 5.16 | 18.93 | 34.20 | 27.04 | 102.5 | 110.0 | .925 | 0 | 0 |

| STATION | DATE | TIME | LATITUDE | LONGITUDE | D |
|---|---|---|---|---|---|
| H 104 | DEC 5, 1963 | 2010-2140 | 37° 22.8'S | 080° 09.9'W | 11 |

OBSERVED AND COMPUTED VALUES AT OBSERVED DEPTHS

| Z (m) | T (°C) | Cl (‰) | S (‰) | $O_2$ (ml/L) | $\sigma_T$ (gm/L) | $\delta_T$ (cl/L) | AOU (ml/L) | $PO_4$ (µg at./L) | $NO_3$ (µg at./L) | $SiO_4$ (µg at./L) | $NO_2$ (µg at./L) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 0 | 15.00 | 18.85 | 34.05 | 6.01 | 25.26 | 271.7 | -.47 | .43 | 6.0 | .9 | .16 |
| 24 | 14.47 | 18.84 | 34.04 | 6.14 | 25.36 | 262.1 | -.54 | .36 | 4.5 | .9 | .11 |
| 48 | 13.74 | 18.79 | 33.95 | 6.14 | 25.45 | 254.2 | -.45 | .38 | 4.6 | 1.0 | .09 |
| 71 | 12.70 | 18.81 | 33.98 | 6.28 | 25.68 | 231.6 | -.47 | .40 | 5.6 | .8 | .12 |
| 95 | 12.08 | 18.81 | 33.98 | 6.15 | 25.80 | 220.3 | -.26 | .50 | 7.0 | .9 | .21 |
| 143 | 11.09 | 18.77 | 33.91 | 5.70 | 25.93 | 208.1 | .32 | .62 | 13.3 | 1.8 | -0 |
| 214 | 8.59 | 18.89 | 34.13 | 4.34 | 26.52 | 152.3 | 2.02 | 1.35 | 24.2 | 8.1 | .02 |
| 306 | 7.10 | 18.96 | 34.25 | 3.99 | 26.84 | 122.1 | 2.59 | 1.65 | 28.8 | 13.1 | .01 |
| 390 | 6.10 | 18.95 | 34.23 | 4.93 | 26.96 | 110.8 | 1.81 | 1.35 | 28.6 | 11.6 | .01 |
| 557 | 5.15 | 18.91 | 34.16 | 5.62 | 27.02 | 105.1 | 1.29 | 1.44 | 27.2 | 13.1 | .01 |

INTERPOLATED AND COMPUTED VALUES AT STANDARD DEPTHS

| Z (m) | T (°C) | Cl (‰) | S (‰) | $\sigma_T$ (gm/L) | $\delta_T$ (cl/T) | $\delta$ (cl/T) | $\Delta D_{Z/0}$ (dyn m) | $\Delta D_{Z/Z\,MAX}$ (dyn m) | $Q_Z$ (m-dynm) |
|---|---|---|---|---|---|---|---|---|---|
| 0 | 15.00 | 18.85 | 34.05 | 25.26 | 271.7 | 271.8 | 0 | .943 | 234.0 |
| 10 | 14.86 | 18.85 | 34.05 | 25.29 | 269.2 | 269.6 | .027 | .916 | 224.7 |
| 20 | 14.62 | 18.84 | 34.04 | 25.33 | 264.9 | 265.6 | .054 | .890 | 215.6 |
| 30 | 14.33 | 18.83 | 34.02 | 25.38 | 260.5 | 261.5 | .080 | .863 | 206.9 |
| 50 | 13.66 | 18.79 | 33.95 | 25.46 | 252.6 | 254.1 | .132 | .812 | 190.1 |
| 75 | 12.58 | 18.81 | 33.98 | 25.70 | 229.5 | 231.6 | .192 | .751 | 170.6 |
| 100 | 11.96 | 18.80 | 33.97 | 25.82 | 218.7 | 221.4 | .249 | .694 | 152.5 |
| 150 | 10.79 | 18.78 | 33.93 | 26.00 | 201.5 | 205.1 | .356 | .588 | 120.5 |
| 200 | 9.01 | 18.87 | 34.08 | 26.42 | 161.7 | 165.8 | .448 | .495 | 93.4 |
| 250 | 7.94 | 18.92 | 34.18 | 26.66 | 139.1 | 143.8 | .526 | .418 | 70.6 |
| 300 | 7.18 | 18.96 | 34.24 | 26.82 | 123.7 | 128.8 | .594 | .350 | 51.4 |
| 400 | 6.03 | 18.95 | 34.23 | 26.96 | 110.4 | 116.1 | .716 | .227 | 22.6 |
| 500 | 5.44 | 18.92 | 34.18 | 27.00 | 106.8 | 113.4 | .831 | .112 | 5.6 |
| 600 | 4.95 | 18.90 | 34.15 | 27.03 | 104.0 | 111.1 | .943 | 0 | 0 |

H 104

| STATION | DATE | TIME | LATITUDE | LONGITUDE | D |
|---|---|---|---|---|---|
| H 105 | DEC 6, 1963 | 0840-0935 | 37° 49.1'S | 082° 14.7'W | 25 |

OBSERVED AND COMPUTED VALUES AT OBSERVED DEPTHS

| Z (m) | T (°C) | Cl (‰) | S (‰) | $O_2$ (ml/L) | $\sigma_T$ (gm/L) | $\delta_T$ (cl/L) | AOU (ml/L) | $PO_4$ (µg at./L) | $NO_3$ (µg at./L) | $SiO_4$ (µg at./L) | $NO_2$ (µg at./L) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 0 | 15.10 | 18.90 | 34.14 | 5.96 | 25.31 | 267.2 | -.43 | .43 | 4.3 | .7 | .14 |
| 25 | 14.94 | 18.86 | 34.07 | 5.98 | 25.29 | 269.1 | -.43 | .37 | 4.0 | .7 | .08 |
| 49 | 13.93 | 18.87 | 34.09 | 6.10 | 25.52 | 247.3 | -.44 | .36 | 4.0 | .8 | .03 |
| 73 | 12.50 | 18.82 | 34.00 | 6.03 | 25.74 | 226.6 | -.19 | .44 | 6.0 | 1.2 | .29 |
| 98 | 11.94 | 18.80 | 33.96 | 5.91 | 25.82 | 219.1 | -.00 | .60 | 8.1 | 1.0 | .49 |
| 147 | 10.92 | 18.79 | 33.95 | 5.91 | 25.99 | 202.6 | .13 | .66 | 10.8 | 1.1 | .33 |
| 221 | 8.68 | 18.88 | 34.11 | 5.22 | 26.49 | 154.9 | 1.13 | 1.18 | 20.4 | 4.1 | .02 |
| 319 | 7.09 | 18.95 | 34.23 | 4.12 | 26.82 | 123.3 | 2.46 | 1.78 | 27.8 | 11.3 | .02 |
| 411 | 6.08 | 18.95 | 34.23 | 4.93 | 26.96 | 110.5 | 1.82 | 1.53 | 27.3 | 11.9 | .01 |
| 590 | 5.18 | 18.92 | 34.18 | 5.59 | 27.03 | 104.1 | 1.31 | 1.63 | 27.5 | 13.0 | .01 |

H 105

INTERPOLATED AND COMPUTED VALUES AT STANDARD DEPTHS

| Z (m) | T (°C) | Cl (‰) | S (‰) | $\sigma_T$ (gm/L) | $\delta_T$ (cl/T) | $\delta$ (cl/T) | $\Delta D_{Z/0}$ (dyn m) | $\Delta D_{Z/Z\,MAX}$ (dyn m) | $Q_Z$ (m-dynm) |
|---|---|---|---|---|---|---|---|---|---|
| 0 | 15.10 | 18.90 | 34.14 | 25.31 | 267.2 | 267.3 | 0 | .952 | 237.0 |
| 10 | 15.06 | 18.88 | 34.11 | 25.29 | 268.6 | 269.0 | .027 | .925 | 227.6 |
| 20 | 14.99 | 18.87 | 34.09 | 25.29 | 269.0 | 269.7 | .054 | .898 | 218.5 |
| 30 | 14.81 | 18.86 | 34.08 | 25.32 | 265.8 | 266.8 | .081 | .872 | 209.6 |
| 50 | 13.88 | 18.87 | 34.09 | 25.53 | 246.6 | 248.1 | .132 | .820 | 192.7 |
| 75 | 12.45 | 18.82 | 34.00 | 25.74 | 225.9 | 228.0 | .192 | .761 | 173.0 |
| 100 | 11.89 | 18.80 | 33.96 | 25.82 | 218.2 | 220.9 | .248 | .705 | 154.6 |
| 150 | 10.81 | 18.79 | 33.95 | 26.01 | 200.2 | 203.8 | .354 | .598 | 122.1 |
| 200 | 9.23 | 18.85 | 34.06 | 26.37 | 166.6 | 170.8 | .448 | .505 | 94.5 |
| 250 | 8.15 | 18.90 | 34.15 | 26.60 | 144.3 | 149.0 | .527 | .425 | 71.2 |
| 300 | 7.36 | 18.94 | 34.21 | 26.77 | 128.6 | 133.8 | .598 | .354 | 51.8 |
| 400 | 6.19 | 18.95 | 34.23 | 26.94 | 111.9 | 117.8 | .724 | .228 | 22.7 |
| 500 | 5.59 | 18.93 | 34.20 | 26.99 | 107.0 | 113.8 | .840 | .112 | 5.6 |
| 600 | 5.14 | 18.92 | 34.18 | 27.03 | 103.8 | 111.2 | .952 | 0 | 0 |

| STATION | DATE | TIME | LATITUDE | LONGITUDE | D |
|---|---|---|---|---|---|
| H 106 | DEC 6, 1963 | 2000-2050 | 38° 06.2′S | 084° 13.2′W | |

OBSERVED AND COMPUTED VALUES AT OBSERVED DEPTHS

| Z (m) | T (°C) | Cl (‰) | S (‰) | $O_2$ (ml/L) | $\sigma_T$ (gm/L) | $\delta_T$ (cl/L) | AOU (ml/L) | $PO_4$ | $NO_3$ | $SiO_4$ | $NO_2$ |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | —— (µg at./L) —— | | | |
| 0 | 14.50 | 18.82 | 34.00 | 5.99 | 25.33 | 265.4 | -.39 | .49 | 6.6 | .7 | .15 |
| 23 | 14.38 | 18.81 | 33.98 | 5.68 | 25.34 | 264.3 | -.06 | .52 | 6.6 | 1.0 | .17 |
| 45 | 13.47 | 18.78 | 33.93 | 6.10 | 25.49 | 250.3 | -.38 | .49 | 7.1 | .9 | .13 |
| 67 | 11.07 | 18.77 | 33.91 | 6.43 | 25.93 | 207.8 | -.41 | .60 | 9.4 | .8 | .17 |
| 90 | 10.49 | 18.75 | 33.87 | 6.18 | 26.01 | 200.7 | -.08 | .73 | 11.4 | 1.2 | .25 |
| 135 | 9.69 | 18.77 | 33.91 | 5.82 | 26.17 | 185.1 | .39 | .82 | 16.1 | 2.0 | .26 |
| 295 | 6.74 | 18.93 | 34.20 | 5.42 | 26.84 | 121.4 | 1.22 | 1.51 | 26.0 | 9.9 | .03 |
| 394 | 5.95 | 18.95 | 34.23 | 4.68 | 26.98 | 108.9 | 2.09 | 1.35 | 26.1 | 10.4 | .01 |
| 471 | 5.54 | 18.93 | 34.20 | 5.71 | 27.00 | 106.8 | 1.13 | 1.35 | 25.4 | 11.6 | .01 |
| 645 | 4.87 | 18.92 | 34.18 | 5.51 | 27.06 | 100.7 | 1.44 | 1.45 | 27.5 | 15.4 | .01 |

INTERPOLATED AND COMPUTED VALUES AT STANDARD DEPTHS

| Z (m) | T (°C) | Cl (‰) | S (‰) | $\sigma_T$ (gm/L) | $\delta_T$ (cl/T) | $\delta$ (cl/T) | $\Delta D_{Z/0}$ (dyn m) | $\Delta D_{Z/Z\,MAX}$ (dyn m) | $Q_Z$ (m-dyn m) |
|---|---|---|---|---|---|---|---|---|---|
| 0 | 14.50 | 18.82 | 34.00 | 25.33 | 265.4 | 265.5 | 0 | 1.009 | 296.9 |
| 10 | 14.47 | 18.82 | 33.99 | 25.33 | 265.1 | 265.5 | .027 | .982 | 286.9 |
| 20 | 14.41 | 18.81 | 33.99 | 25.34 | 264.5 | 265.2 | .053 | .956 | 277.3 |
| 30 | 14.19 | 18.80 | 33.97 | 25.37 | 261.5 | 262.4 | .079 | .929 | 267.8 |
| 50 | 13.02 | 18.77 | 33.92 | 25.57 | 242.4 | 243.8 | .130 | .879 | 249.7 |
| 75 | 10.85 | 18.76 | 33.90 | 25.96 | 205.1 | 207.0 | .186 | .822 | 228.5 |
| 100 | 10.28 | 18.75 | 33.88 | 26.05 | 196.7 | 199.0 | .237 | .771 | 208.6 |
| 150 | 9.29 | 18.79 | 33.94 | 26.26 | 176.5 | 179.7 | .332 | .677 | 172.4 |
| 200 | 8.21 | 18.84 | 34.04 | 26.51 | 153.1 | 157.0 | .416 | .593 | 140.6 |
| 250 | 7.37 | 18.89 | 34.13 | 26.70 | 134.9 | 139.3 | .490 | .519 | 112.9 |
| 300 | 6.69 | 18.93 | 34.20 | 26.85 | 120.7 | 125.5 | .556 | .452 | 88.6 |
| 400 | 5.92 | 18.95 | 34.23 | 26.98 | 108.8 | 114.5 | .676 | .332 | 49.3 |
| 500 | 5.41 | 18.93 | 34.19 | 27.01 | 105.7 | 112.2 | .790 | .219 | 21.8 |
| 600 | 5.02 | 18.92 | 34.18 | 27.05 | 102.1 | 109.4 | .900 | .108 | 5.4 |
| 700 | 4.70 | 18.92 | 34.18 | 27.08 | 99.1 | 107.1 | 1.009 | 0 | 0 |

| STATION | DATE | TIME | LATITUDE | LONGITUDE | D |
|---|---|---|---|---|---|
| H 107 | DEC 7, 1963 | 0830-0920 | 38° 45.5′S | 086° 24.2′W | 23 |

OBSERVED AND COMPUTED VALUES AT OBSERVED DEPTHS

| Z (m) | T (°C) | Cl (‰) | S (‰) | $O_2$ (ml/L) | $\sigma_T$ (gm/L) | $\delta_T$ (cl/L) | AOU (ml/L) | $PO_4$ | $NO_3$ | $SiO_4$ | $NO_2$ |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | —— (µg at./L) —— | | | |
| 0 | 13.80 | 18.84 | 34.04 | 6.07 | 25.50 | 248.8 | -.39 | .62 | 6.2 | .7 | .16 |
| 25 | 13.72 | 18.90 | 34.14 | 6.07 | 25.60 | 239.2 | -.38 | .46 | 6.0 | .7 | .12 |
| 49 | 13.39 | 18.91 | 34.16 | 6.13 | 25.69 | 231.5 | -.41 | .47 | 5.8 | .7 | .10 |
| 73 | 11.33 | 18.85 | 34.05 | 6.41 | 26.00 | 201.6 | -.43 | .62 | 8.1 | .5 | .18 |
| 98 | 10.91 | 18.83 | 34.02 | 6.14 | 26.05 | 197.1 | -.10 | .64 | 9.4 | .6 | .27 |
| 147 | 10.33 | 999.00 | 999.00 | 6.19 | 999.00 | 999.0 | 999.00 | .67 | 11.9 | .7 | .47 |
| 190 | 9.72 | 18.86 | 34.07 | 5.35 | 26.30 | 173.5 | .85 | .91 | 15.8 | 1.3 | .07 |
| 289 | 7.16 | 18.97 | 34.27 | 5.78 | 26.84 | 121.5 | .79 | 1.42 | 22.8 | 5.6 | .01 |
| 387 | 6.11 | 19.00 | 34.33 | 5.52 | 27.03 | 104.1 | 1.22 | 1.36 | 24.2 | 8.4 | .03 |
| 573 | 5.27 | 18.99 | 34.31 | 5.74 | 27.12 | 95.7 | 1.14 | 1.43 | 25.6 | 11.2 | .01 |

INTERPOLATED AND COMPUTED VALUES AT STANDARD DEPTHS

| Z (m) | T (°C) | Cl (‰) | S (‰) | $\sigma_T$ (gm/L) | $\delta_T$ (cl/T) | $\delta$ (cl/T) | $\Delta D_{Z/0}$ (dyn m) | $\Delta D_{Z/Z\,MAX}$ (dyn m) | $Q_Z$ (m-dyn m) |
|---|---|---|---|---|---|---|---|---|---|
| 0 | 13.80 | 18.84 | 34.04 | 25.50 | 248.8 | 248.9 | 0 | .884 | 220.8 |
| 10 | 13.78 | 18.85 | 34.06 | 25.53 | 246.4 | 246.8 | .025 | .859 | 212.1 |
| 20 | 13.75 | 18.88 | 34.11 | 25.57 | 242.4 | 243.1 | .049 | .835 | 203.6 |
| 30 | 13.68 | 18.90 | 34.15 | 25.62 | 237.9 | 238.9 | .073 | .811 | 195.4 |
| 50 | 13.33 | 18.91 | 34.16 | 25.69 | 230.5 | 232.0 | .120 | .764 | 179.6 |
| 75 | 11.29 | 18.85 | 34.05 | 26.00 | 201.2 | 203.1 | .175 | .709 | 161.2 |
| 100 | 10.88 | 18.83 | 34.02 | 26.05 | 196.4 | 198.8 | .225 | .659 | 144.1 |
| 150 | 10.28 | 18.86 | 34.08 | 26.21 | 182.0 | 185.4 | .321 | .563 | 113.5 |
| 200 | 9.41 | 18.87 | 34.09 | 26.36 | 167.2 | 171.5 | .410 | .474 | 87.6 |
| 250 | 8.05 | 18.93 | 34.19 | 26.65 | 139.5 | 144.2 | .489 | .395 | 65.9 |
| 300 | 7.03 | 18.97 | 34.28 | 26.87 | 119.3 | 124.3 | .556 | .328 | 47.9 |
| 400 | 6.04 | 19.00 | 34.32 | 27.03 | 103.4 | 109.2 | .673 | .211 | 20.9 |
| 500 | 5.56 | 18.99 | 34.31 | 27.08 | 98.6 | 105.3 | .780 | .104 | 5.2 |
| 600 | 5.17 | 18.99 | 34.30 | 27.13 | 94.7 | 102.1 | .884 | 0 | 0 |

| STATION | DATE | TIME | LATITUDE | LONGITUDE | D |
|---|---|---|---|---|---|
| H 108 | DEC 7, 1963 | 2000-2055 | 39° 36.5'S | 088° 22.0'W | |

OBSERVED AND COMPUTED VALUES AT OBSERVED DEPTHS

| Z | T | Cl | S | $O_2$ | $\sigma_T$ | $\delta_T$ | AOU | $PO_4$ | $NO_3$ | $SiO_4$ | $NO_2$ |
|---|---|---|---|---|---|---|---|---|---|---|---|
| (m) | (°C) | (‰) | (‰) | (ml/L) | (gm/L) | (cl/L) | (ml/L) | (µg at./L) | | | |
| 0 | 14.30 | 18.87 | 34.09 | 6.06 | 25.44 | 254.7 | -.44 | .58 | 7.4 | .8 | .19 |
| 25 | 13.36 | 18.86 | 34.07 | 6.18 | 25.62 | 237.5 | -.45 | .58 | 7.8 | .5 | .16 |
| 50 | 11.94 | 18.83 | 34.02 | 6.50 | 25.86 | 215.1 | -.59 | .53 | 8.1 | .7 | .19 |
| 75 | 10.57 | 18.83 | 34.02 | 6.50 | 26.11 | 191.4 | -.41 | .63 | 10.3 | .6 | .19 |
| 100 | 10.24 | 18.81 | 33.98 | 6.33 | 26.14 | 188.6 | -.20 | .79 | 11.4 | .7 | .24 |
| 150 | 9.92 | 18.82 | 34.00 | 6.19 | 26.21 | 182.1 | -.01 | .76 | 12.6 | .8 | .22 |
| 200 | 8.99 | 18.87 | 34.09 | 5.89 | 26.43 | 160.9 | .41 | 1.02 | 18.1 | 1.9 | .03 |
| 299 | 999.00 | 18.95 | 34.23 | 5.33 | 999.00 | 999.0 | 999.00 | 1.44 | 24.6 | 6.6 | .01 |
| 399 | 6.04 | 19.01 | 34.34 | 5.65 | 27.05 | 101.9 | 1.10 | -0 | -0 | -0 | -0 |
| 584 | 5.25 | 19.00 | 34.33 | 5.84 | 27.13 | 94.1 | 1.04 | 1.50 | 26.1 | 11.4 | .01 |

H 108

INTERPOLATED AND COMPUTED VALUES AT STANDARD DEPTHS

| Z (m) | T (°C) | Cl (‰) | S (‰) | $\sigma_T$ (gm/L) | $\delta_T$ (cl/T) | $\delta$ (cl/T) | $\Delta D_{Z/0}$ (dyn m) | $\Delta D_{Z/Z\,MAX}$ (dyn m) | $Q_Z$ (m-dynm) |
|---|---|---|---|---|---|---|---|---|---|
| 0 | 14.30 | 18.87 | 34.09 | 25.44 | 254.7 | 254.9 | 0 | .875 | 219.9 |
| 10 | 14.06 | 18.87 | 34.08 | 25.48 | 250.4 | 250.8 | .025 | .850 | 211.3 |
| 20 | 13.67 | 18.86 | 34.08 | 25.56 | 243.3 | 243.9 | .050 | .825 | 202.9 |
| 30 | 13.12 | 18.85 | 34.06 | 25.66 | 233.6 | 234.6 | .074 | .801 | 194.7 |
| 50 | 11.94 | 18.83 | 34.02 | 25.86 | 215.1 | 216.5 | .119 | .756 | 179.2 |
| 75 | 10.57 | 18.83 | 34.02 | 26.11 | 191.4 | 193.2 | .170 | .705 | 160.9 |
| 100 | 10.24 | 18.81 | 33.98 | 26.14 | 188.6 | 190.9 | .218 | .657 | 143.9 |
| 150 | 9.92 | 18.82 | 34.00 | 26.20 | 182.1 | 185.5 | .312 | .563 | 113.4 |
| 200 | 8.99 | 18.87 | 34.09 | 26.43 | 160.9 | 165.0 | .400 | .475 | 87.4 |
| 250 | 8.04 | 18.91 | 34.16 | 26.63 | 141.9 | 146.5 | .478 | .397 | 65.6 |
| 300 | 7.26 | 18.94 | 34.22 | 26.79 | 126.3 | 131.4 | .547 | .328 | 47.5 |
| 400 | 6.03 | 19.01 | 34.34 | 27.05 | 101.9 | 107.7 | .667 | .208 | 20.7 |
| 500 | 5.57 | 19.00 | 34.33 | 27.10 | 97.3 | 104.0 | .773 | .103 | 5.1 |
| 600 | 5.19 | 19.00 | 34.32 | 27.14 | 93.5 | 101.0 | .875 | 0 | 0 |

| STATION | DATE | TIME | LATITUDE | LONGITUDE | D |
|---|---|---|---|---|---|
| H 109 | DEC 8, 1963 | 0606-0657 | 40° 32.8'S | 089° 43.8'W | 25 |

OBSERVED AND COMPUTED VALUES AT OBSERVED DEPTHS

| Z | T | Cl | S | $O_2$ | $\sigma_T$ | $\delta_T$ | AOU | $PO_4$ | $NO_3$ | $SiO_4$ | $NO_2$ |
|---|---|---|---|---|---|---|---|---|---|---|---|
| (m) | (°C) | (‰) | (‰) | (ml/L) | (gm/L) | (cl/L) | (ml/L) | (µg at./L) | | | |
| 0 | 12.90 | 18.84 | 34.04 | 6.21 | 25.69 | 231.4 | -.42 | .86 | 12.0 | 2.1 | .38 |
| 25 | 12.41 | 18.83 | 34.02 | 6.25 | 25.77 | 223.6 | -.40 | .76 | 10.6 | 1.1 | .18 |
| 50 | 11.84 | 18.83 | 34.02 | 6.33 | 25.88 | 213.3 | -.41 | .76 | 10.6 | .8 | .18 |
| 75 | 10.28 | 18.81 | 33.98 | 6.36 | 26.13 | 189.2 | -.23 | .71 | 10.2 | .8 | .22 |
| 100 | 9.85 | 18.82 | 34.00 | 6.22 | 26.22 | 181.0 | -.03 | .94 | 13.6 | .9 | .33 |
| 150 | 8.89 | 18.90 | 34.14 | 5.71 | 26.49 | 155.4 | .61 | 1.02 | 16.0 | 2.3 | .06 |
| 198 | 7.58 | 18.93 | 34.20 | 5.66 | 26.73 | 132.6 | .85 | 1.31 | 22.5 | 4.0 | .02 |
| 298 | 6.29 | 18.98 | 34.29 | 5.59 | 26.98 | 109.0 | 1.12 | 1.60 | 25.5 | 7.5 | .02 |
| 394 | 5.84 | 18.96 | 34.25 | 5.81 | 27.00 | 106.3 | .98 | 1.56 | 25.1 | 8.8 | .02 |
| 583 | 5.18 | 18.97 | 34.27 | 5.87 | 27.10 | 97.4 | 1.03 | 1.49 | 26.8 | 11.3 | .01 |

H 109

INTERPOLATED AND COMPUTED VALUES AT STANDARD DEPTHS

| Z (m) | T (°C) | Cl (‰) | S (‰) | $\sigma_T$ (gm/L) | $\delta_T$ (cl/T) | $\delta$ (cl/T) | $\Delta D_{Z/0}$ (dyn m) | $\Delta D_{Z/Z\,MAX}$ (dyn m) | $Q_Z$ (m-dynm) |
|---|---|---|---|---|---|---|---|---|---|
| 0 | 12.90 | 18.84 | 34.04 | 25.68 | 231.4 | 231.5 | 0 | .820 | 211.2 |
| 10 | 12.78 | 18.84 | 34.03 | 25.71 | 229.5 | 229.9 | .023 | .797 | 203.1 |
| 20 | 12.57 | 18.83 | 34.02 | 25.74 | 226.2 | 226.9 | .046 | .774 | 195.3 |
| 30 | 12.32 | 18.83 | 34.02 | 25.78 | 222.0 | 222.9 | .068 | .752 | 187.7 |
| 50 | 11.84 | 18.83 | 34.02 | 25.88 | 213.3 | 214.7 | .112 | .708 | 173.1 |
| 75 | 10.28 | 18.81 | 33.98 | 26.13 | 189.2 | 191.0 | .163 | .657 | 156.0 |
| 100 | 9.85 | 18.82 | 34.00 | 26.22 | 181.0 | 183.2 | .210 | .611 | 140.1 |
| 150 | 8.89 | 18.90 | 34.14 | 26.49 | 155.4 | 158.5 | .295 | .525 | 111.7 |
| 200 | 7.55 | 18.93 | 34.20 | 26.73 | 132.0 | 135.6 | .369 | .452 | 87.3 |
| 250 | 6.84 | 18.96 | 34.25 | 26.87 | 119.1 | 123.2 | .433 | .387 | 66.4 |
| 300 | 6.28 | 18.98 | 34.29 | 26.97 | 109.0 | 113.5 | .492 | .328 | 48.5 |
| 400 | 5.81 | 18.96 | 34.25 | 27.01 | 105.9 | 111.5 | .605 | .215 | 21.3 |
| 500 | 5.44 | 18.97 | 34.26 | 27.06 | 100.9 | 107.4 | .714 | .106 | 5.3 |
| 600 | 5.13 | 18.97 | 34.27 | 27.10 | 96.7 | 104.1 | .820 | 0 | 0 |

| STATION | DATE | TIME | LATITUDE | LONGITUDE | D |
|---|---|---|---|---|---|
| H 110 | DEC. 8, 1963 | 2000-2045 | 39° 28.0'S | 090° 35.5'W | |

OBSERVED AND COMPUTED VALUES AT OBSERVED DEPTHS

| Z (m) | T (°C) | Cl (‰) | S (‰) | $O_2$ (ml/L) | $\sigma_T$ (gm/L) | $\delta_T$ (cl/L) | AOU (ml/L) | $PO_4$ (µg at./L) | $NO_3$ (µg at./L) | $SiO_4$ (µg at./L) | $NO_2$ (µg at./L) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 0 | 13.90 | 18.83 | 34.02 | 5.97 | 25.47 | 252.0 | -.30 | .61 | 9.0 | 1.0 | .24 |
| 24 | 13.46 | 18.85 | 34.05 | 6.00 | 25.59 | 240.8 | -.28 | .57 | 8.5 | .8 | .15 |
| 49 | 13.23 | 18.83 | 34.02 | 5.99 | 25.61 | 239.0 | -.24 | .68 | 8.5 | .7 | .15 |
| 73 | 10.80 | 18.83 | 34.02 | 6.39 | 26.07 | 195.2 | -.33 | .74 | 9.4 | .7 | .20 |
| 97 | 10.23 | 18.84 | 34.04 | 6.00 | 26.18 | 184.4 | .13 | .93 | 12.5 | .9 | .30 |
| 146 | 8.56 | 18.91 | 34.16 | 5.44 | 26.55 | 149.1 | .92 | .92 | 12.9 | .9 | .30 |
| 216 | 7.06 | 18.94 | 34.22 | 5.38 | 26.81 | 124.2 | 1.21 | 1.52 | 23.7 | 5.3 | .02 |
| 316 | 6.30 | 19.01 | 34.34 | 5.23 | 27.02 | 105.1 | 1.48 | 1.72 | 26.1 | 7.5 | .02 |
| 410 | 5.87 | 19.01 | 34.34 | 5.60 | 27.07 | 99.9 | 1.18 | 1.64 | 26.1 | 9.4 | .02 |
| 598 | 5.13 | 19.01 | 34.34 | 5.78 | 27.16 | 91.4 | 1.12 | 1.72 | 27.7 | 12.8 | .02 |

INTERPOLATED AND COMPUTED VALUES AT STANDARD DEPTHS

| Z (m) | T (°C) | Cl (‰) | S (‰) | $\sigma_T$ (gm/L) | $\delta_T$ (cl/T) | $\delta$ (cl/T) | $\Delta D_{Z/0}$ (dyn m) | $\Delta D_{Z/Z\,MAX}$ (dyn m) | $Q_Z$ (m-dynm) |
|---|---|---|---|---|---|---|---|---|---|
| 0 | 13.90 | 18.83 | 34.02 | 25.47 | 252.0 | 252.2 | 0 | .814 | 204.0 |
| 10 | 13.78 | 18.83 | 34.03 | 25.50 | 249.1 | 249.5 | .025 | .789 | 196.0 |
| 20 | 13.59 | 18.84 | 34.04 | 25.55 | 244.0 | 244.7 | .050 | .764 | 188.2 |
| 30 | 13.41 | 18.85 | 34.05 | 25.59 | 240.4 | 241.3 | .074 | .740 | 180.7 |
| 50 | 13.16 | 18.83 | 34.02 | 25.62 | 237.7 | 239.2 | .122 | .692 | 166.4 |
| 75 | 10.75 | 18.83 | 34.02 | 26.08 | 194.2 | 196.1 | .177 | .637 | 149.8 |
| 100 | 10.11 | 18.84 | 34.04 | 26.21 | 181.8 | 184.1 | .224 | .590 | 134.4 |
| 150 | 8.46 | 18.91 | 34.16 | 26.57 | 147.4 | 150.4 | .308 | .506 | 107.0 |
| 200 | 7.35 | 18.93 | 34.20 | 26.76 | 129.1 | 132.6 | .378 | .435 | 83.5 |
| 250 | 6.77 | 18.97 | 34.26 | 26.89 | 116.9 | 120.9 | .442 | .372 | 63.3 |
| 300 | 6.40 | 19.00 | 34.32 | 26.99 | 107.7 | 112.3 | .500 | .314 | 46.2 |
| 400 | 5.91 | 19.01 | 34.34 | 27.07 | 100.4 | 106.1 | .609 | .204 | 20.3 |
| 500 | 5.48 | 19.01 | 34.34 | 27.12 | 95.4 | 102.0 | .713 | .100 | 5.0 |
| 600 | 5.12 | 19.01 | 34.34 | 27.16 | 91.3 | 98.7 | .814 | 0 | 0 |

| STATION | DATE | TIME | LATITUDE | LONGITUDE | D |
|---|---|---|---|---|---|
| H 111 | DEC 9, 1963 | 0833-0933 | 37° 53.0'S | 092° 08.5'W | 17 |

OBSERVED AND COMPUTED VALUES AT OBSERVED DEPTHS

| Z (m) | T (°C) | Cl (‰) | S (‰) | $O_2$ (ml/L) | $\sigma_T$ (gm/L) | $\delta_T$ (cl/L) | AOU (ml/L) | $PO_4$ (µg at./L) | $NO_3$ (µg at./L) | $SiO_4$ (µg at./L) | $NO_2$ (µg at./L) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 0 | 14.80 | 18.88 | 34.11 | 5.79 | 25.35 | 263.6 | -.23 | .52 | 5.0 | .9 | .22 |
| 25 | 14.67 | 18.91 | 34.16 | 5.82 | 25.42 | 257.0 | -.24 | .71 | 5.3 | .5 | .11 |
| 50 | 14.29 | 18.90 | 34.14 | 5.82 | 25.48 | 250.6 | -.20 | .38 | 4.4 | .5 | .10 |
| 75 | 12.37 | 18.87 | 34.09 | 6.08 | 25.83 | 217.6 | -.23 | .42 | 5.4 | .5 | .15 |
| 100 | 11.59 | 18.86 | 34.07 | 5.90 | 25.97 | 204.9 | .05 | .63 | 8.0 | .6 | .27 |
| 150 | 10.18 | 18.83 | 34.02 | 5.95 | 26.18 | 184.9 | .19 | .67 | 11.7 | .9 | .32 |
| 224 | 8.31 | 18.95 | 34.23 | 5.26 | 26.65 | 140.1 | 1.14 | 1.32 | 20.7 | 3.5 | .02 |
| 324 | 6.66 | 19.00 | 34.33 | 5.09 | 26.95 | 111.0 | 1.56 | 1.60 | 25.5 | 7.5 | .02 |
| 419 | 6.18 | 18.99 | 34.31 | 5.34 | 27.00 | 106.3 | 1.39 | 1.63 | 25.9 | 8.8 | .02 |
| 604 | 5.39 | 18.97 | 34.27 | 5.46 | 27.07 | 99.7 | 1.40 | -0 | -0 | -0 | -0 |

INTERPOLATED AND COMPUTED VALUES AT STANDARD DEPTHS

| Z (m) | T (°C) | Cl (‰) | S (‰) | $\sigma_T$ (gm/L) | $\delta_T$ (cl/T) | $\delta$ (cl/T) | $\Delta D_{Z/0}$ (dyn m) | $\Delta D_{Z/Z\,MAX}$ (dyn m) | $Q_Z$ (m-dynm) |
|---|---|---|---|---|---|---|---|---|---|
| 0 | 14.80 | 18.88 | 34.11 | 25.35 | 263.6 | 263.7 | 0 | .903 | 224.5 |
| 10 | 14.77 | 18.89 | 34.12 | 25.36 | 261.9 | 262.3 | .026 | .876 | 215.6 |
| 20 | 14.71 | 18.90 | 34.14 | 25.39 | 259.2 | 259.9 | .052 | .850 | 207.0 |
| 30 | 14.62 | 18.91 | 34.16 | 25.43 | 255.9 | 256.9 | .078 | .824 | 198.6 |
| 50 | 14.29 | 18.90 | 34.14 | 25.48 | 250.6 | 252.1 | .129 | .773 | 182.6 |
| 75 | 12.37 | 18.87 | 34.09 | 25.83 | 217.6 | 219.6 | .188 | .714 | 164.0 |
| 100 | 11.59 | 18.86 | 34.07 | 25.96 | 204.9 | 207.4 | .242 | .661 | 146.8 |
| 150 | 10.18 | 18.83 | 34.02 | 26.17 | 184.9 | 188.4 | .340 | .562 | 116.3 |
| 200 | 8.64 | 18.91 | 34.17 | 26.51 | 152.8 | 156.9 | .427 | .476 | 90.3 |
| 250 | 7.82 | 18.96 | 34.26 | 26.74 | 131.5 | 136.0 | .500 | .403 | 68.3 |
| 300 | 7.00 | 18.99 | 34.30 | 26.89 | 117.1 | 122.0 | .565 | .338 | 49.8 |
| 400 | 6.27 | 18.99 | 34.31 | 26.99 | 107.2 | 113.2 | .682 | .220 | 21.9 |
| 500 | 5.80 | 18.98 | 34.29 | 27.04 | 103.1 | 110.1 | .794 | .109 | 5.4 |
| 600 | 5.40 | 18.97 | 34.27 | 27.07 | 99.8 | 107.6 | .903 | 0 | 0 |

| STATION | DATE | TIME | LATITUDE | LONGITUDE | D |
|---|---|---|---|---|---|
| H 112 | DEC 10, 1963 | 0830-0945 | 36° 02.1'S | 093° 45.9'W | 18 |

OBSERVED AND COMPUTED VALUES AT OBSERVED DEPTHS

| Z (m) | T (°C) | Cl (‰) | S (‰) | $O_2$ (ml/L) | $\sigma_T$ (gm/L) | $\delta_T$ (cl/L) | AOU (ml/L) | $PO_4$ (μg at./L) | $NO_3$ (μg at./L) | $SiO_4$ (μg at./L) | $NO_2$ (μg at./L) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 0 | 15.50 | 18.98 | 34.29 | 5.64 | 25.33 | 265.0 | -.16 | .44 | 3.6 | .6 | .18 |
| 25 | 15.49 | 18.98 | 34.29 | 5.72 | 25.33 | 264.8 | -.24 | .32 | 3.2 | .4 | .06 |
| 50 | 15.31 | 18.98 | 34.29 | 5.70 | 25.37 | 261.0 | -.20 | .32 | 3.0 | .5 | .06 |
| 75 | 13.17 | 18.93 | 34.20 | 6.27 | 25.76 | 224.6 | -.52 | .43 | 4.0 | .5 | .09 |
| 100 | 12.45 | 18.88 | 34.11 | 6.21 | 25.83 | 217.7 | -.37 | .53 | 5.7 | .5 | .14 |
| 150 | 11.18 | 18.88 | 34.11 | 5.77 | 26.07 | 195.0 | .23 | .64 | 9.8 | .7 | .41 |
| 225 | 9.74 | 18.93 | 34.20 | 5.32 | 26.39 | 164.5 | .87 | .87 | 10.3 | 1.6 | .07 |
| 324 | 7.28 | 18.98 | 34.29 | 5.18 | 26.84 | 121.8 | 1.37 | 1.49 | 23.6 | 5.3 | .02 |
| 398 | 6.49 | 19.00 | 34.33 | 5.35 | 26.98 | 108.8 | 1.33 | 1.60 | 24.7 | 7.4 | .02 |
| 583 | 5.56 | 19.03 | 34.38 | 5.64 | 27.14 | 93.5 | 1.19 | 1.52 | 25.9 | 10.5 | .02 |

INTERPOLATED AND COMPUTED VALUES AT STANDARD DEPTHS

H 112

| Z (m) | T (°C) | Cl (‰) | S (‰) | $\sigma_T$ (gm/L) | $\delta_T$ (cl/T) | $\delta$ (cl/T) | $\Delta D_{Z/0}$ (dyn m) | $\Delta D_{Z/Z\,MAX}$ (dyn m) | $Q_Z$ (m-dynm) |
|---|---|---|---|---|---|---|---|---|---|
| 0 | 15.50 | 18.98 | 34.29 | 25.33 | 265.0 | 265.1 | 0 | .945 | 231.4 |
| 10 | 15.50 | 18.98 | 34.29 | 25.33 | 265.0 | 265.4 | .027 | .919 | 222.0 |
| 20 | 15.49 | 18.98 | 34.29 | 25.33 | 264.9 | 265.6 | .053 | .892 | 213.0 |
| 30 | 15.47 | 18.98 | 34.29 | 25.34 | 264.4 | 265.4 | .080 | .866 | 204.2 |
| 50 | 15.31 | 18.98 | 34.29 | 25.37 | 261.0 | 262.6 | .132 | .813 | 187.4 |
| 75 | 13.17 | 18.93 | 34.20 | 25.76 | 224.6 | 226.8 | .194 | .752 | 167.8 |
| 100 | 12.45 | 18.88 | 34.11 | 25.83 | 217.7 | 220.4 | .249 | .696 | 149.7 |
| 150 | 11.18 | 18.88 | 34.11 | 26.07 | 195.0 | 198.7 | .354 | .591 | 117.6 |
| 200 | 10.16 | 18.91 | 34.17 | 26.30 | 173.4 | 177.9 | .448 | .497 | 90.4 |
| 250 | 9.03 | 18.94 | 34.22 | 26.52 | 152.2 | 157.3 | .532 | .413 | 67.6 |
| 300 | 7.80 | 18.97 | 34.26 | 26.74 | 130.8 | 136.2 | .606 | .340 | 48.8 |
| 400 | 6.48 | 19.00 | 34.33 | 26.98 | 108.6 | 114.8 | .731 | .214 | 21.1 |
| 500 | 5.93 | 19.02 | 34.36 | 27.07 | 99.7 | 106.8 | .842 | .104 | 5.2 |
| 600 | 5.49 | 19.03 | 34.38 | 27.15 | 92.4 | 100.3 | .945 | 0 | 0 |

| STATION | DATE | TIME | LATITUDE | LONGITUDE | D |
|---|---|---|---|---|---|
| H 113 | DEC 10, 1963 | 2010-2052 | 35° 19.0'S | 094° 35.3'W | |

OBSERVED AND COMPUTED VALUES AT OBSERVED DEPTHS

| Z (m) | T (°C) | Cl (‰) | S (‰) | $O_2$ (ml/L) | $\sigma_T$ (gm/L) | $\delta_T$ (cl/L) | AOU (ml/L) | $PO_4$ (μg at./L) | $NO_3$ (μg at./L) | $SiO_4$ (μg at./L) | $NO_2$ (μg at./L) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 0 | 16.70 | 19.09 | 34.49 | 5.55 | 25.21 | 276.6 | -.20 | .25 | 1.2 | .5 | .09 |
| 25 | 16.53 | 19.12 | 34.54 | 5.56 | 25.29 | 268.9 | -.20 | .20 | .6 | .3 | .03 |
| 50 | 15.99 | 19.11 | 34.52 | 5.69 | 25.40 | 258.4 | -.27 | .19 | .7 | .3 | .03 |
| 75 | 14.77 | 19.20 | 34.69 | 5.76 | 25.80 | 220.7 | -.21 | .15 | .6 | .3 | .05 |
| 100 | 14.54 | 19.15 | 34.60 | 5.73 | 25.78 | 222.6 | -.16 | .20 | 1.1 | .4 | .11 |
| 150 | 13.35 | 19.05 | 34.42 | 5.56 | 25.89 | 212.2 | .16 | .31 | 3.3 | .4 | .24 |
| 225 | 10.68 | 19.05 | 34.42 | 4.96 | 26.40 | 163.9 | 1.09 | .83 | 14.3 | 1.7 | .03 |
| 323 | 7.83 | 19.00 | 34.33 | 4.96 | 26.79 | 126.6 | 1.51 | 1.24 | 21.9 | 4.8 | .05 |
| 427 | 6.46 | 19.02 | 34.36 | 5.14 | 27.01 | 105.7 | 1.54 | 1.52 | 26.1 | 8.0 | .02 |
| 609 | 5.58 | 18.98 | 34.29 | 5.58 | 27.06 | 100.5 | 1.25 | 1.48 | -0 | 10.8 | .04 |

H 113

INTERPOLATED AND COMPUTED VALUES AT STANDARD DEPTHS

| Z (m) | T (°C) | Cl (‰) | S (‰) | $\sigma_T$ (gm/L) | $\delta_T$ (cl/T) | $\delta$ (cl/T) | $\Delta D_{Z/0}$ (dyn m) | $\Delta D_{Z/Z\,MAX}$ (dyn m) | $Q_Z$ (m-dynm) |
|---|---|---|---|---|---|---|---|---|---|
| 0 | 16.70 | 19.09 | 34.49 | 25.21 | 276.6 | 276.7 | 0 | .974 | 239.6 |
| 10 | 16.66 | 19.10 | 34.50 | 25.23 | 274.7 | 275.1 | .028 | .946 | 230.0 |
| 20 | 16.59 | 19.11 | 34.52 | 25.26 | 271.5 | 272.2 | .055 | .919 | 220.7 |
| 30 | 16.46 | 19.12 | 34.54 | 25.31 | 267.3 | 268.4 | .082 | .892 | 211.6 |
| 50 | 15.99 | 19.11 | 34.52 | 25.40 | 258.4 | 260.1 | .135 | .839 | 194.3 |
| 75 | 14.77 | 19.20 | 34.69 | 25.80 | 220.7 | 223.0 | .195 | .778 | 174.1 |
| 100 | 14.54 | 19.15 | 34.60 | 25.78 | 222.6 | 225.6 | .251 | .722 | 155.3 |
| 150 | 13.35 | 19.05 | 34.41 | 25.89 | 212.2 | 216.4 | .362 | .612 | 122.0 |
| 200 | 11.46 | 19.04 | 34.41 | 26.25 | 177.9 | 182.9 | .462 | .512 | 93.9 |
| 250 | 9.85 | 19.03 | 34.38 | 26.51 | 153.0 | 158.5 | .547 | .427 | 70.4 |
| 300 | 8.41 | 19.00 | 34.33 | 26.71 | 134.2 | 140.0 | .622 | .352 | 50.9 |
| 400 | 6.78 | 19.01 | 34.35 | 26.96 | 110.6 | 117.0 | .750 | .224 | 22.2 |
| 500 | 6.07 | 19.00 | 34.33 | 27.03 | 103.4 | 110.7 | .864 | .110 | 5.5 |
| 600 | 5.62 | 18.98 | 34.29 | 27.06 | 100.8 | 108.8 | .974 | 0 | 0 |

| STATION | DATE | TIME | LATITUDE | LONGITUDE | D |
|---|---|---|---|---|---|
| H 114 | DEC 11, 1963 | 0558-0640 | 34° 17.5'S | 094° 32.6'W | 30 |

OBSERVED AND COMPUTED VALUES AT OBSERVED DEPTHS

| Z (m) | T (°C) | Cl (‰) | S (‰) | $O_2$ (ml/L) | $\sigma_T$ (gm/L) | $\delta_T$ (cl/L) | AOU (ml/L) | $PO_4$ | $NO_3$ | $SiO_4$ | $NO_2$ |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | —— | (µg at./L) | | —— |
| 0 | 16.80 | 19.11 | 34.52 | 5.25 | 25.21 | 276.2 | .09 | .48 | 1.5 | .6 | .09 |
| 25 | 16.78 | 19.12 | 34.54 | 5.51 | 25.23 | 274.5 | -.17 | .21 | .9 | .3 | .02 |
| 50 | 16.42 | 19.14 | 34.58 | 5.60 | 25.35 | 263.8 | -.23 | .19 | .6 | .4 | .02 |
| 75 | 14.13 | 19.03 | 34.38 | 6.01 | 25.70 | 230.2 | -.38 | .23 | 1.4 | .4 | .05 |
| 100 | 14.08 | 19.09 | 34.49 | 5.75 | 25.79 | 221.2 | -.12 | .26 | 1.7 | .4 | .10 |
| 149 | 12.87 | 19.01 | 34.34 | 5.55 | 25.93 | 208.3 | .23 | .40 | 5.1 | .5 | .27 |
| 193 | 11.38 | 18.98 | 34.29 | 5.39 | 26.17 | 185.2 | .58 | .60 | 10.7 | .7 | .18 |
| 293 | 8.59 | 19.01 | 34.34 | 5.19 | 26.69 | 136.2 | 1.16 | 1.05 | 19.7 | 3.0 | .01 |
| 394 | 7.03 | 999.00a) | 999.00 | 4.60 | 999.00 | 999.0 | 999.00 | 1.12 | -0 | -0 | -0 |
| 581 | 5.67 | 18.99 | 34.31 | 5.84 | 27.07 | 100.2 | .97 | 1.30 | 26.7 | 10.2 | .01 |

H 11

INTERPOLATED AND COMPUTED VALUES AT STANDARD DEPTHS

| Z (m) | T (°C) | Cl (‰) | S (‰) | $\sigma_T$ (gm/L) | $\delta_T$ (cl/T) | $\delta$ (cl/T) | $\Delta D_{Z/0}$ (dyn m) | $\Delta D_{Z/Z\,MAX}$ (dyn m) | $Q_Z$ (m-dynm) |
|---|---|---|---|---|---|---|---|---|---|
| 0 | 16.80 | 19.11 | 34.52 | 25.21 | 276.2 | 276.3 | 0 | .992 | 245.7 |
| 10 | 16.80 | 19.11 | 34.53 | 25.22 | 275.8 | 276.2 | .028 | .964 | 235.9 |
| 20 | 16.79 | 19.12 | 34.54 | 25.23 | 275.0 | 275.8 | .055 | .937 | 226.4 |
| 30 | 16.74 | 19.12 | 34.55 | 25.25 | 273.1 | 274.2 | .083 | .909 | 217.2 |
| 50 | 16.42 | 19.14 | 34.58 | 25.34 | 263.8 | 265.5 | .137 | .855 | 199.5 |
| 75 | 14.13 | 19.03 | 34.38 | 25.70 | 230.2 | 232.4 | .199 | .793 | 178.9 |
| 100 | 14.08 | 19.09 | 34.49 | 25.79 | 221.2 | 224.2 | .256 | .736 | 159.8 |
| 150 | 12.83 | 19.01 | 34.34 | 25.93 | 207.7 | 211.8 | .365 | .627 | 125.8 |
| 200 | 11.14 | 18.98 | 34.29 | 26.22 | 181.0 | 185.9 | .464 | .527 | 96.9 |
| 250 | 9.65 | 18.99 | 34.31 | 26.49 | 154.8 | 160.3 | .551 | .441 | 72.7 |
| 300 | 8.47 | 19.01 | 34.33 | 26.70 | 134.9 | 140.8 | .626 | .366 | 52.6 |
| 400 | 6.98 | 18.96 | 34.26 | 26.86 | 119.8 | 126.4 | .760 | .232 | 22.7 |
| 500 | 6.20 | 18.98 | 34.28 | 26.98 | 108.1 | 115.5 | .881 | .111 | 5.5 |
| 600 | 5.56 | 18.99 | 34.31 | 27.08 | 98.5 | 106.5 | .992 | 0 | 0 |

| STATION | DATE | TIME | LATITUDE | LONGITUDE | D |
|---|---|---|---|---|---|
| H 115 | DEC 11, 1963 | 2210-2254 | 33° 13.6'S | 094° 52.7'W | |

OBSERVED AND COMPUTED VALUES AT OBSERVED DEPTHS

| Z (m) | T (°C) | Cl (‰) | S (‰) | $O_2$ (ml/L) | $\sigma_T$ (gm/L) | $\delta_T$ (cl/L) | AOU (ml/L) | $PO_4$ | $NO_3$ | $SiO_4$ | $NO_2$ |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | —— | (µg at./L) | | —— |
| 0 | 17.20 | 19.23 | 34.74 | 5.39 | 25.29 | 269.5 | -.10 | .27 | 1.0 | .5 | .06 |
| 24 | 17.44 | 19.23 | 34.74 | 5.46 | 25.23 | 274.9 | -.20 | .19 | .3 | .3 | .01 |
| 48 | 16.81 | 19.22 | 34.72 | 5.56 | 25.36 | 262.0 | -.23 | .18 | .2 | .3 | .01 |
| 72 | 15.79 | 19.22 | 34.72 | 5.72 | 25.60 | 239.6 | -.29 | .16 | .2 | .3 | 0 |
| 96 | 15.40 | 19.19 | 34.67 | 5.65 | 25.65 | 235.2 | -.17 | .18 | .4 | .3 | .03 |
| 144 | 14.95 | 19.18 | 34.65 | 5.42 | 25.73 | 227.1 | .11 | .22 | .4 | .4 | .13 |
| 208 | 12.65 | 19.04 | 34.40 | 4.82 | 26.01 | 200.2 | .98 | .57 | 9.8 | 1.1 | .02 |
| 313 | 8.77 | 18.95 | 34.23 | 4.92 | 26.58 | 146.9 | 1.41 | 1.27 | 19.6 | 3.3 | .01 |
| 403 | 6.86 | 18.93 | 34.20 | 4.81 | 26.83 | 123.0 | 1.81 | 1.58 | 25.4 | 8.0 | .01 |
| 579 | 5.79 | 18.95 | 34.23 | 5.36 | 27.00 | 107.0 | 1.43 | 1.75 | 27.1 | 10.3 | .01 |

H 11

INTERPOLATED AND COMPUTED VALUES AT STANDARD DEPTHS

| Z (m) | T (°C) | Cl (‰) | S (‰) | $\sigma_T$ (gm/L) | $\delta_T$ (cl/T) | $\delta$ (cl/T) | $\Delta D_{Z/0}$ (dyn m) | $\Delta D_{Z/Z\,MAX}$ (dyn m) | $Q_Z$ (m-dynm) |
|---|---|---|---|---|---|---|---|---|---|
| 0 | 17.20 | 19.23 | 34.74 | 25.28 | 269.5 | 269.6 | 0 | 1.054 | 263.1 |
| 10 | 17.38 | 19.23 | 34.74 | 25.24 | 273.5 | 274.0 | .027 | 1.027 | 252.7 |
| 20 | 17.43 | 19.23 | 34.74 | 25.23 | 274.6 | 275.4 | .055 | 1.000 | 242.6 |
| 30 | 17.33 | 19.23 | 34.74 | 25.25 | 272.6 | 273.7 | .082 | .972 | 232.7 |
| 50 | 16.74 | 19.22 | 34.72 | 25.38 | 260.4 | 262.1 | .136 | .919 | 213.8 |
| 75 | 15.73 | 19.22 | 34.71 | 25.61 | 239.0 | 241.4 | .199 | .856 | 191.7 |
| 100 | 15.35 | 19.19 | 34.67 | 25.65 | 234.4 | 237.5 | .258 | .796 | 171.0 |
| 150 | 14.69 | 19.16 | 34.62 | 25.76 | 224.1 | 228.6 | .375 | .679 | 134.1 |
| 200 | 12.90 | 19.05 | 34.42 | 25.98 | 203.1 | 208.5 | .484 | .570 | 102.9 |
| 250 | 10.90 | 18.99 | 34.30 | 26.27 | 176.2 | 182.2 | .582 | .472 | 76.8 |
| 300 | 9.17 | 18.95 | 34.24 | 26.52 | 152.4 | 158.6 | .667 | .387 | 55.4 |
| 400 | 6.92 | 18.93 | 34.20 | 26.82 | 123.7 | 130.2 | .812 | .243 | 23.9 |
| 500 | 6.22 | 18.94 | 34.22 | 26.93 | 113.5 | 120.9 | .937 | .117 | 5.9 |
| 600 | 5.68 | 18.95 | 34.24 | 27.01 | 105.5 | 113.6 | 1.054 | 0 | 0 |

| STATION | DATE | TIME | LATITUDE | LONGITUDE | D |
|---|---|---|---|---|---|
| H 116 | DEC 12, 1963 | 0600-0654 | 31° 59.0'S | 094° 52.7'W | 31 |

OBSERVED AND COMPUTED VALUES AT OBSERVED DEPTHS

| Z | T | Cl | S | $O_2$ | $\sigma_T$ | $\delta_T$ | AOU | $PO_4$ | $NO_3$ | $SiO_4$ | $NO_2$ |
|---|---|---|---|---|---|---|---|---|---|---|---|
| (m) | (°C) | (‰) | (‰) | (ml/L) | (gm/L) | (cl/L) | (ml/L) | (μg at./L) | | | |
| 0 | 18.10 | 19.28 | 34.83 | 5.38 | 25.14 | 283.7 | -.18 | .29 | .8 | .6 | .03 |
| 25 | 17.94 | 19.27 | 34.81 | 5.37 | 25.16 | 281.3 | -.16 | .17 | .3 | .4 | .01 |
| 50 | 17.09 | 19.29 | 34.85 | 5.54 | 25.40 | 259.1 | -.24 | .16 | .2 | .4 | 0 |
| 74 | 16.50 | 19.29 | 34.85 | 5.58 | 25.53 | 245.9 | -.23 | .17 | .3 | .3 | 0 |
| 99 | 15.61 | 19.23 | 34.74 | 5.67 | 25.65 | 234.4 | -.22 | .17 | .2 | .3 | .01 |
| 149 | 14.79 | 19.16 | 34.61 | 5.46 | 25.74 | 226.4 | .09 | .22 | 2.6 | .5 | .23 |
| 208 | 12.46 | 19.01 | 34.34 | 5.09 | 26.01 | 200.6 | .74 | .78 | -0 | -0 | -0 |
| 308 | 9.52 | 18.98 | 34.29 | 4.55 | 26.50 | 154.4 | 1.67 | 1.08 | 18.8 | 3.7 | .01 |
| 404 | 7.03 | 18.96 | 34.25 | 4.53 | 26.85 | 121.1 | 2.06 | 1.37 | 26.1 | 8.6 | .01 |
| 590 | 5.61 | 18.91 | 34.16 | 5.40 | 26.96 | 110.3 | 1.43 | 1.46 | 26.2 | 11.0 | .01 |

INTERPOLATED AND COMPUTED VALUES AT STANDARD DEPTHS

H 116

| Z | T | Cl | S | $\sigma_T$ | $\delta_T$ | $\delta$ | $\Delta D_{Z/0}$ | $\Delta D_{Z/Z\,MAX}$ | $Q_Z$ |
|---|---|---|---|---|---|---|---|---|---|
| (m) | (°C) | (‰) | (‰) | (gm/L) | (cl/T) | (cl/T) | (dyn m) | (dyn m) | (m-dyn m) |
| 0 | 18.10 | 19.28 | 34.83 | 25.14 | 283.7 | 283.8 | 0 | 1.068 | 266.7 |
| 10 | 18.06 | 19.28 | 34.83 | 25.14 | 283.1 | 283.5 | .028 | 1.040 | 256.1 |
| 20 | 17.99 | 19.27 | 34.82 | 25.15 | 282.1 | 282.9 | .057 | 1.012 | 245.9 |
| 30 | 17.83 | 19.27 | 34.81 | 25.19 | 278.6 | 279.7 | .085 | .983 | 235.9 |
| 50 | 17.09 | 19.29 | 34.85 | 25.39 | 259.1 | 260.8 | .139 | .929 | 216.8 |
| 75 | 16.47 | 19.29 | 34.84 | 25.54 | 245.5 | 247.9 | .202 | .866 | 194.3 |
| 100 | 15.60 | 19.23 | 34.74 | 25.65 | 234.2 | 237.4 | .263 | .805 | 173.4 |
| 150 | 14.76 | 19.16 | 34.61 | 25.74 | 226.0 | 230.5 | .380 | .688 | 136.1 |
| 200 | 12.76 | 19.03 | 34.37 | 25.97 | 203.9 | 209.3 | .490 | .578 | 104.5 |
| 250 | 11.08 | 18.99 | 34.30 | 26.24 | 179.0 | 185.0 | .589 | .480 | 78.0 |
| 300 | 9.72 | 18.98 | 34.29 | 26.46 | 157.5 | 164.0 | .676 | .392 | 56.2 |
| 400 | 7.12 | 18.96 | 34.25 | 26.83 | 122.4 | 129.0 | .822 | .246 | 24.3 |
| 500 | 6.23 | 18.93 | 34.20 | 26.91 | 115.1 | 122.4 | .948 | .120 | 6.0 |
| 600 | 5.55 | 18.91 | 34.16 | 26.97 | 109.9 | 117.8 | 1.068 | 0 | 0 |

| STATION | DATE | TIME | LATITUDE | LONGITUDE | D |
|---|---|---|---|---|---|
| H 117 | DEC 12, 1963 | 1400-1450 | 30° 28.7'S | 094° 48.0'W | 32 |

OBSERVED AND COMPUTED VALUES AT OBSERVED DEPTHS

| Z | T | Cl | S | $O_2$ | $\sigma_T$ | $\delta_T$ | AOU | $PO_4$ | $NO_3$ | $SiO_4$ | $NO_2$ |
|---|---|---|---|---|---|---|---|---|---|---|---|
| (m) | (°C) | (‰) | (‰) | (ml/L) | (gm/L) | (cl/L) | (ml/L) | (μg at./L) | | | |
| 0 | 18.70 | 19.33 | 34.92 | 5.33 | 25.06 | 291.4 | -.19 | .22 | .6 | .5 | .02 |
| 25 | 18.37 | 19.31 | 34.88 | 5.35 | 25.11 | 286.1 | -.18 | .22 | .2 | .3 | .01 |
| 50 | 17.27 | 19.32 | 34.90 | 5.45 | 25.39 | 259.2 | -.17 | .21 | .2 | .3 | .01 |
| 75 | 16.56 | 19.24 | 34.76 | 5.62 | 25.45 | 253.8 | -.27 | .21 | .2 | .4 | .01 |
| 100 | 15.59 | 19.22 | 34.72 | 5.69 | 25.65 | 235.3 | -.24 | .23 | 1.3 | .3 | .05 |
| 149 | 14.85 | 19.18 | 34.65 | 5.40 | 25.75 | 225.0 | .14 | .22 | 1.7 | .4 | .17 |
| 197 | 13.87 | 19.10 | 34.51 | 5.27 | 25.85 | 215.7 | .38 | .33 | 4.6 | .5 | .29 |
| 297 | 10.33 | 19.00 | 34.33 | 4.56 | 26.39 | 164.7 | 1.55 | 1.10 | 17.3 | 3.1 | .01 |
| 393 | 7.94 | 19.02 | 34.36 | 3.11 | 26.80 | 125.5 | 3.34 | 1.84 | 30.0 | 14.4 | .01 |
| 578 | 5.76 | 18.96 | 34.25 | 5.29 | 27.01 | 105.3 | 1.51 | 1.41 | 27.0 | 10.7 | .01 |

H 117

INTERPOLATED AND COMPUTED VALUES AT STANDARD DEPTHS

| Z | T | Cl | S | $\sigma_T$ | $\delta_T$ | $\delta$ | $\Delta D_{Z/0}$ | $\Delta D_{Z/Z\,MAX}$ | $Q_Z$ |
|---|---|---|---|---|---|---|---|---|---|
| (m) | (°C) | (‰) | (‰) | (gm/L) | (cl/T) | (cl/T) | (dyn m) | (dyn m) | (m-dyn m) |
| 0 | 18.70 | 19.33 | 34.92 | 25.05 | 291.4 | 291.5 | 0 | 1.083 | 268.7 |
| 10 | 18.62 | 19.32 | 34.91 | 25.07 | 290.1 | 290.5 | .029 | 1.054 | 258.0 |
| 20 | 18.48 | 19.32 | 34.90 | 25.09 | 287.9 | 288.7 | .058 | 1.025 | 247.6 |
| 30 | 18.20 | 19.31 | 34.88 | 25.15 | 282.1 | 283.2 | .087 | .997 | 237.5 |
| 50 | 17.27 | 19.32 | 34.90 | 25.39 | 259.2 | 261.0 | .141 | .942 | 218.1 |
| 75 | 16.56 | 19.24 | 34.76 | 25.45 | 253.8 | 256.3 | .206 | .878 | 195.3 |
| 100 | 15.59 | 19.22 | 34.72 | 25.64 | 235.3 | 238.4 | .268 | .816 | 174.2 |
| 150 | 14.83 | 19.18 | 34.65 | 25.75 | 224.8 | 229.3 | .385 | .699 | 136.3 |
| 200 | 13.74 | 19.09 | 34.50 | 25.87 | 213.9 | 219.5 | .497 | .587 | 104.2 |
| 250 | 11.82 | 19.03 | 34.38 | 26.16 | 186.1 | 192.5 | .600 | .484 | 77.4 |
| 300 | 10.24 | 19.00 | 34.32 | 26.40 | 163.3 | 170.1 | .690 | .393 | 55.5 |
| 400 | 7.84 | 19.02 | 34.35 | 26.81 | 124.5 | 131.8 | .841 | .242 | 23.7 |
| 500 | 6.58 | 18.98 | 34.28 | 26.93 | 112.9 | 120.6 | .967 | .116 | 5.8 |
| 600 | 5.55 | 18.96 | 34.25 | 27.03 | 103.4 | 111.3 | 1.083 | 0 | 0 |

| STATION | DATE | TIME | LATITUDE | LONGITUDE | D |
|---|---|---|---|---|---|
| H 118 | DEC 12, 1963 | 2015-2100 | 29° 55.8S | 094° 58.5W | |

OBSERVED AND COMPUTED VALUES AT OBSERVED DEPTHS

| Z (m) | T (°C) | Cl (‰) | S (‰) | $O_2$ (ml/L) | $\sigma_T$ (gm/L) | $\delta_T$ (cl/L) | AOU (ml/L) | $PO_4$ | $NO_3$ (µg at./L) | $SiO_4$ | $NO_2$ |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 0 | 19.50 | 19.50 | 35.23 | 5.20 | 25.08 | 288.6 | -.15 | .19 | .5 | .5 | .02 |
| 25 | 19.42 | 19.53 | 35.28 | 5.23 | 25.15 | 282.7 | -.17 | .18 | .2 | .3 | .01 |
| 50 | 18.56 | 19.53 | 35.28 | 5.34 | 25.37 | 261.8 | -.20 | .12 | .3 | .4 | .01 |
| 75 | 17.79 | 19.54 | 35.30 | 5.42 | 25.57 | 242.3 | -.21 | .13 | .1 | .4 | .01 |
| 100 | 17.54 | 19.49 | 35.21 | 5.39 | 25.56 | 243.1 | -.15 | .21 | .2 | .3 | 0 |
| 150 | 16.89 | 19.44 | 35.12 | 5.26 | 25.65 | 234.8 | .05 | .17 | .6 | .3 | .13 |
| 200 | 16.33 | 19.35 | 34.96 | 5.22 | 25.66 | 234.2 | .15 | .19 | 1.2 | .3 | .34 |
| 297 | 12.17 | 19.13 | 34.56 | 4.65 | 26.23 | 179.4 | 1.21 | .65 | 11.9 | .7 | .01 |
| 393 | 8.38 | 19.01 | 34.34 | 4.18 | 26.72 | 133.1 | 2.20 | 1.38 | 28.9 | 7.5 | .01 |
| 578 | 5.88 | 18.97 | 34.27 | 5.01 | 27.01 | 105.4 | 1.77 | 1.42 | 28.8 | 11.2 | .01 |

INTERPOLATED AND COMPUTED VALUES AT STANDARD DEPTHS

| Z (m) | T (°C) | Cl (‰) | S (‰) | $\sigma_T$ (gm/L) | $\delta_T$ (cl/T) | $\delta$ (cl/T) | $\Delta D_{Z/0}$ (dyn m) | $\Delta D_{Z/Z\,MAX}$ (dyn m) | $Q_Z$ (m-dyn m) |
|---|---|---|---|---|---|---|---|---|---|
| 0 | 19.50 | 19.50 | 35.23 | 25.08 | 288.6 | 288.7 | 0 | 1.131 | 282.5 |
| 10 | 19.48 | 19.51 | 35.24 | 25.10 | 287.1 | 287.6 | .029 | 1.102 | 271.3 |
| 20 | 19.45 | 19.52 | 35.26 | 25.12 | 284.7 | 285.5 | .057 | 1.074 | 260.5 |
| 30 | 19.32 | 19.53 | 35.28 | 25.17 | 279.9 | 281.1 | .086 | 1.045 | 249.9 |
| 50 | 18.56 | 19.53 | 35.28 | 25.37 | 261.8 | 263.6 | .140 | .991 | 229.5 |
| 75 | 17.79 | 19.54 | 35.30 | 25.57 | 242.3 | 244.9 | .204 | .927 | 205.5 |
| 100 | 17.54 | 19.49 | 35.21 | 25.56 | 243.1 | 246.5 | .265 | .866 | 183.1 |
| 150 | 16.89 | 19.44 | 35.12 | 25.65 | 234.8 | 239.8 | .387 | .744 | 142.8 |
| 200 | 16.33 | 19.35 | 34.96 | 25.66 | 234.2 | 240.6 | .507 | .624 | 108.6 |
| 250 | 14.18 | 19.22 | 34.72 | 25.95 | 205.9 | 213.1 | .620 | .511 | 80.2 |
| 300 | 12.03 | 19.12 | 34.55 | 26.25 | 177.7 | 185.4 | .720 | .411 | 57.2 |
| 400 | 8.27 | 19.01 | 34.34 | 26.73 | 131.8 | 139.4 | .882 | .249 | 24.2 |
| 500 | 6.82 | 18.98 | 34.29 | 26.90 | 115.8 | 123.8 | 1.014 | .117 | 5.9 |
| 600 | 5.64 | 18.97 | 34.27 | 27.04 | 102.7 | 110.8 | 1.131 | 0 | 0 |

| STATION | DATE | TIME | LATITUDE | LONGITUDE | D |
|---|---|---|---|---|---|
| H 119 | DEC 13, 1963 | 0625-0710 | 29° 55.2S | 094° 29.8W | 38 |

OBSERVED AND COMPUTED VALUES AT OBSERVED DEPTHS

| Z (m) | T (°C) | Cl (‰) | S (‰) | $O_2$ (ml/L) | $\sigma_T$ (gm/L) | $\delta_T$ (cl/L) | AOU (ml/L) | $PO_4$ | $NO_3$ (µg at./L) | $SiO_4$ | $NO_2$ |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 0 | 19.30 | 19.43 | 35.10 | 5.25 | 25.04 | 292.8 | -.17 | .23 | 1.3 | .6 | .05 |
| 25 | 19.10 | 19.41 | 35.07 | 5.37 | 25.06 | 290.6 | -.27 | .15 | 0 | .3 | .01 |
| 50 | 18.39 | 19.42 | 35.08 | 5.36 | 25.26 | 272.2 | -.20 | .17 | 0 | .4 | .01 |
| 75 | 17.05 | 19.32 | 34.90 | 5.54 | 25.45 | 254.2 | -.24 | .15 | 0 | .3 | .01 |
| 100 | 16.81 | 19.31 | 34.88 | 5.54 | 25.49 | 250.1 | -.22 | .18 | .3 | .6 | .03 |
| 150 | 16.46 | 19.34 | 34.94 | 5.29 | 25.61 | 238.4 | .07 | .17 | .5 | .4 | .14 |
| 199 | 16.38 | 19.34 | 34.94 | 5.28 | 25.63 | 236.6 | .08 | .18 | .9 | .4 | .31 |
| 293 | 12.31 | 19.01 | 34.34 | 4.75 | 26.04 | 197.9 | 1.10 | .88 | 12.0 | 1.8 | .02 |
| 392 | 8.59 | 18.98 | 34.29 | 3.87 | 26.65 | 140.2 | 2.48 | 1.31 | 22.7 | 8.1 | .02 |
| 585 | 5.92 | 18.94 | 34.22 | 5.18 | 26.97 | 109.9 | 1.59 | 1.41 | 27.4 | 10.6 | .01 |

INTERPOLATED AND COMPUTED VALUES AT STANDARD DEPTHS

| Z (m) | T (°C) | Cl (‰) | S (‰) | $\sigma_T$ (gm/L) | $\delta_T$ (cl/T) | $\delta$ (cl/T) | $\Delta D_{Z/0}$ (dyn m) | $\Delta D_{Z/Z\,MAX}$ (dyn m) | $Q_Z$ (m-dynm) |
|---|---|---|---|---|---|---|---|---|---|
| 0 | 19.30 | 19.43 | 35.10 | 25.04 | 292.8 | 293.0 | 0 | 1.176 | 295.7 |
| 10 | 19.25 | 19.42 | 35.09 | 25.04 | 292.3 | 292.7 | .029 | 1.147 | 284.1 |
| 20 | 19.17 | 19.42 | 35.08 | 25.05 | 291.3 | 292.1 | .059 | 1.117 | 272.8 |
| 30 | 19.01 | 19.41 | 35.06 | 25.09 | 288.3 | 289.5 | .088 | 1.088 | 261.8 |
| 50 | 18.39 | 19.42 | 35.08 | 25.26 | 272.2 | 274.0 | .144 | 1.032 | 240.6 |
| 75 | 17.05 | 19.32 | 34.90 | 25.44 | 254.2 | 256.8 | .210 | .965 | 215.6 |
| 100 | 16.81 | 19.31 | 34.88 | 25.49 | 250.1 | 253.4 | .274 | .902 | 192.3 |
| 150 | 16.46 | 19.34 | 34.94 | 25.61 | 238.4 | 243.2 | .398 | .778 | 150.3 |
| 200 | 16.33 | 19.33 | 34.93 | 25.64 | 236.1 | 242.5 | .520 | .656 | 114.5 |
| 250 | 13.98 | 19.13 | 34.56 | 25.87 | 213.8 | 220.9 | .636 | .540 | 84.6 |
| 300 | 12.01 | 19.00 | 34.33 | 26.09 | 193.2 | 200.8 | .741 | .435 | 60.2 |
| 400 | 8.46 | 18.98 | 34.28 | 26.66 | 138.7 | 146.4 | .915 | .261 | 25.4 |
| 500 | 6.97 | 18.95 | 34.23 | 26.84 | 121.8 | 129.9 | 1.053 | .123 | 6.2 |
| 600 | 5.75 | 18.94 | 34.22 | 26.98 | 108.0 | 116.2 | 1.176 | 0 | 0 |

H 120

| STATION | DATE | TIME | LATITUDE | LONGITUDE | D |
|---|---|---|---|---|---|
| H 120 | DEC 13, 1963 | 2210-2304 | 28° 37.0'S | 094° 55.7'W | |

OBSERVED AND COMPUTED VALUES AT OBSERVED DEPTHS

| Z (m) | T (°C) | Cl (‰) | S (‰) | $O_2$ (ml/L) | $\sigma_T$ (gm/L) | $\delta_T$ (cl/L) | AOU (ml/L) | $PO_4$ (µg at./L) | $NO_3$ (µg at./L) | $SiO_4$ (µg at./L) | $NO_2$ (µg at./L) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 0 | 20.20 | 19.56 | 35.34 | 5.14 | 24.98 | 298.2 | -.15 | .22 | 1.2 | .6 | .07 |
| 25 | 20.05 | 19.53 | 35.28 | 5.16 | 24.98 | 298.4 | -.16 | .17 | 0 | .3 | .01 |
| 50 | 19.52 | 19.54 | 35.30 | 5.29 | 25.13 | 283.9 | -.24 | .19 | 0 | .3 | .01 |
| 75 | 18.34 | 19.47 | 35.17 | 5.38 | 25.34 | 264.4 | -.22 | .17 | 0 | .3 | .01 |
| 100 | 17.60 | 19.41 | 35.07 | 5.34 | 25.44 | 255.0 | -.10 | .15 | 0 | .3 | .02 |
| 150 | 17.06 | 19.38 | 35.01 | 5.22 | 25.53 | 246.6 | .07 | .17 | .4 | .4 | .11 |
| 200 | 15.78 | 19.26 | 34.79 | 4.92 | 25.66 | 234.1 | .51 | .32 | 3.3 | .6 | .13 |
| 293 | 10.81 | 18.96 | 34.25 | 4.29 | 26.25 | 178.1 | 1.75 | 1.09 | 17.5 | 3.8 | .01 |
| 391 | 8.31 | 18.98 | 34.29 | 3.06 | 26.69 | 136.1 | 3.33 | 1.75 | 29.0 | 13.6 | .01 |
| 574 | 5.84 | 18.97 | 34.27 | 4.73 | 27.02 | 104.9 | 2.05 | 1.64 | 29.0 | 13.2 | .01 |

INTERPOLATED AND COMPUTED VALUES AT STANDARD DEPTHS

| Z (m) | T (°C) | Cl (‰) | S (‰) | $\sigma_T$ (gm/L) | $\delta_T$ (cl/T) | $\delta$ (cl/T) | $\Delta D_{Z/0}$ (dyn m) | $\Delta D_{Z/Z\,MAX}$ (dyn m) | $Q_Z$ (m-dynm) |
|---|---|---|---|---|---|---|---|---|---|
| 0 | 20.20 | 19.56 | 35.34 | 24.98 | 298.2 | 298.4 | 0 | 1.155 | 284.1 |
| 10 | 20.16 | 19.55 | 35.32 | 24.98 | 298.3 | 298.8 | .030 | 1.125 | 272.7 |
| 20 | 20.10 | 19.54 | 35.30 | 24.98 | 298.4 | 299.2 | .060 | 1.095 | 261.6 |
| 30 | 19.98 | 19.53 | 35.29 | 25.00 | 296.3 | 297.5 | .090 | 1.066 | 250.8 |
| 50 | 19.52 | 19.54 | 35.30 | 25.13 | 283.9 | 285.7 | .148 | 1.007 | 230.0 |
| 75 | 18.34 | 19.47 | 35.17 | 25.34 | 264.4 | 267.1 | .217 | .938 | 205.7 |
| 100 | 17.60 | 19.41 | 35.06 | 25.44 | 255.0 | 258.4 | .283 | .872 | 183.1 |
| 150 | 17.06 | 19.38 | 35.01 | 25.53 | 246.6 | 251.5 | .410 | .745 | 142.7 |
| 200 | 15.78 | 19.26 | 34.79 | 25.66 | 234.1 | 240.3 | .533 | .622 | 108.5 |
| 250 | 13.09 | 19.08 | 34.46 | 25.98 | 203.8 | 210.6 | .646 | .509 | 80.2 |
| 300 | 10.61 | 18.96 | 34.25 | 26.28 | 174.6 | 181.6 | .744 | .411 | 57.2 |
| 400 | 8.16 | 18.98 | 34.28 | 26.71 | 134.3 | 141.7 | .906 | .250 | 24.1 |
| 500 | 6.73 | 18.97 | 34.27 | 26.90 | 116.1 | 124.0 | 1.038 | .117 | 5.8 |
| 600 | 5.55 | 18.97 | 34.27 | 27.06 | 101.3 | 109.3 | 1.155 | 0 | 0 |

H 121

| STATION | DATE | TIME | LATITUDE | LONGITUDE | D |
|---|---|---|---|---|---|
| H 121 | DEC 14, 1963 | 0600-0645 | 27° 16.2'S | 094° 55.5'W | 34 |

OBSERVED AND COMPUTED VALUES AT OBSERVED DEPTHS

| Z (m) | T (°C) | Cl (‰) | S (‰) | $O_2$ (ml/L) | $\sigma_T$ (gm/L) | $\delta_T$ (cl/L) | AOU (ml/L) | $PO_4$ (µg at./L) | $NO_3$ (µg at./L) | $SiO_4$ (µg at./L) | $NO_2$ (µg at./L) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 0 | 20.60 | 19.57 | 35.35 | 5.09 | 24.89 | 307.1 | -.14 | .20 | .3 | .5 | .01 |
| 25 | 20.13 | 19.56 | 35.34 | 5.15 | 25.00 | 296.5 | -.16 | .18 | 0 | .3 | .01 |
| 49 | 19.48 | 19.56 | 35.34 | 999.00 | 25.17 | 280.3 | 999.00 | .17 | 0 | .3 | 0 |
| 74 | 18.59 | 19.49 | 35.21 | 5.32 | 25.30 | 267.8 | -.18 | .18 | 0 | .3 | 0 |
| 99 | 17.73 | 19.41 | 35.07 | 5.37 | 25.41 | 258.0 | -.15 | -0 | -0 | -0 | -0 |
| 148 | 16.85 | 19.36 | 34.97 | 5.29 | 25.55 | 244.5 | .02 | .20 | .9 | .5 | .09 |
| 208 | 13.73 | 19.09 | 34.49 | 4.74 | 25.87 | 214.3 | .93 | .53 | 8.3 | 1.2 | .02 |
| 298 | 9.81 | 18.99 | 34.31 | 3.27 | 26.46 | 157.6 | 2.91 | 1.33 | 23.7 | 10.1 | 0 |
| 398 | 7.64 | 18.96 | 34.25 | 3.27 | 26.76 | 129.3 | 3.23 | 1.55 | 23.6 | 10.2 | 0 |
| 580 | 5.67 | 18.93 | 34.20 | 4.92 | 26.98 | 108.3 | 1.90 | 1.75 | 30.8 | 14.1 | 0 |

INTERPOLATED AND COMPUTED VALUES AT STANDARD DEPTHS

| Z (m) | T (°C) | Cl (‰) | S (‰) | $\sigma_T$ (gm/L) | $\delta_T$ (cl/T) | $\delta$ (cl/T) | $\Delta D_{Z/0}$ (dyn m) | $\Delta D_{Z/Z\,MAX}$ (dyn m) | $Q_Z$ (m-dynm) |
|---|---|---|---|---|---|---|---|---|---|
| 0 | 20.60 | 19.57 | 35.35 | 24.89 | 307.1 | 307.2 | 0 | 1.121 | 274.8 |
| 10 | 20.48 | 19.57 | 35.35 | 24.92 | 304.4 | 304.9 | .031 | 1.090 | 263.7 |
| 20 | 20.29 | 19.56 | 35.34 | 24.96 | 300.0 | 300.9 | .061 | 1.060 | 252.9 |
| 30 | 20.03 | 19.56 | 35.33 | 25.03 | 294.0 | 295.1 | .091 | 1.030 | 242.5 |
| 50 | 19.45 | 19.56 | 35.33 | 25.18 | 279.8 | 281.7 | .148 | .973 | 222.5 |
| 75 | 18.56 | 19.49 | 35.20 | 25.31 | 267.4 | 270.1 | .217 | .904 | 199.0 |
| 100 | 17.71 | 19.41 | 35.06 | 25.41 | 257.8 | 261.2 | .284 | .837 | 177.2 |
| 150 | 16.76 | 19.35 | 34.96 | 25.56 | 243.6 | 248.4 | .411 | .710 | 138.6 |
| 200 | 14.12 | 19.12 | 34.54 | 25.83 | 218.1 | 223.9 | .529 | .592 | 106.0 |
| 250 | 11.73 | 19.02 | 34.37 | 26.17 | 185.3 | 191.6 | .633 | .488 | 79.0 |
| 300 | 9.76 | 18.99 | 34.30 | 26.47 | 157.0 | 163.5 | .722 | .399 | 56.8 |
| 400 | 7.61 | 18.96 | 34.25 | 26.76 | 129.1 | 136.1 | .872 | .249 | 24.4 |
| 500 | 6.45 | 18.94 | 34.21 | 26.89 | 116.6 | 124.2 | 1.002 | .119 | 6.0 |
| 600 | 5.49 | 18.93 | 34.20 | 27.00 | 106.4 | 114.3 | 1.121 | 0 | 0 |

| STATION | DATE | TIME | LATITUDE | LONGITUDE | D |
|---|---|---|---|---|---|
| H 122 | DEC 14, 1963 | 1200-1246 | 26° 13.6'S | 094° 53.2'W | 38 |

OBSERVED AND COMPUTED VALUES AT OBSERVED DEPTHS

| Z (m) | T (°C) | Cl (‰) | S (‰) | $O_2$ (ml/L) | $\sigma_T$ (gm/L) | $\delta_T$ (cl/L) | AOU (ml/L) | $PO_4$ (µg at./L) | $NO_3$ (µg at./L) | $SiO_4$ (µg at./L) | $NO_2$ (µg at./L) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 0 | 21.50 | 19.65 | 35.50 | 5.07 | 24.75 | 320.0 | -.20 | .21 | .4 | .5 | .02 |
| 25 | 20.79 | 19.63 | 35.46 | 4.79 | 24.92 | 304.1 | .14 | .23 | 0 | .3 | 0 |
| 50 | 19.25 | 19.53 | 35.28 | 5.44 | 25.19 | 278.5 | -.37 | .15 | 0 | .4 | 0 |
| 74 | 18.48 | 19.51 | 35.25 | 5.32 | 25.36 | 262.5 | -.17 | .14 | 0 | .3 | 0 |
| 99 | 17.95 | 19.49 | 35.21 | 5.28 | 25.46 | 252.6 | -.08 | .23 | 0 | .3 | 0 |
| 148 | 16.77 | 19.36 | 34.97 | 5.42 | 25.57 | 242.7 | -.10 | .27 | 1.2 | .5 | .19 |
| 231 | 14.61 | 19.20 | 34.69 | 4.91 | 25.83 | 217.4 | .65 | .42 | 5.1 | .8 | .05 |
| 328 | 9.41 | 18.98 | 34.29 | 4.16 | 26.52 | 152.6 | 2.07 | 1.20 | 19.8 | 5.9 | 0 |
| 418 | 7.79 | 19.03 | 34.38 | 2.17 | 26.84 | 122.0 | 4.30 | 1.96 | 32.2 | 18.9 | 0 |
| 601 | 5.51 | 18.96 | 34.25 | 5.16 | 27.04 | 102.4 | 1.68 | 2.05 | 32.2 | 17.2 | .01 |

INTERPOLATED AND COMPUTED VALUES AT STANDARD DEPTHS

| Z (m) | T (°C) | Cl (‰) | S (‰) | $\sigma_T$ (gm/L) | $\delta_T$ (cl/T) | $\delta$ (cl/T) | $\Delta D_{Z/0}$ (dyn m) | $\Delta D_{Z/Z\,MAX}$ (dyn m) | $Q_Z$ (m-dynm) |
|---|---|---|---|---|---|---|---|---|---|
| 0 | 21.50 | 19.65 | 35.50 | 24.75 | 320.0 | 320.1 | 0 | 1.136 | 277.0 |
| 10 | 21.32 | 19.64 | 35.49 | 24.80 | 316.0 | 316.5 | .032 | 1.104 | 265.8 |
| 20 | 21.03 | 19.64 | 35.47 | 24.86 | 309.4 | 310.3 | .063 | 1.073 | 254.9 |
| 30 | 20.54 | 19.61 | 35.43 | 24.97 | 299.8 | 301.0 | .094 | 1.042 | 244.3 |
| 50 | 19.25 | 19.53 | 35.28 | 25.19 | 278.5 | 280.4 | .152 | .984 | 224.1 |
| 75 | 18.46 | 19.51 | 35.24 | 25.36 | 262.1 | 264.7 | .220 | .916 | 200.3 |
| 100 | 17.92 | 19.49 | 35.20 | 25.46 | 252.4 | 255.8 | .285 | .851 | 178.2 |
| 150 | 16.70 | 19.35 | 34.96 | 25.57 | 241.9 | 246.8 | .411 | .725 | 138.8 |
| 200 | 15.31 | 19.25 | 34.77 | 25.75 | 225.6 | 231.7 | .530 | .605 | 105.6 |
| 250 | 13.44 | 19.13 | 34.57 | 25.99 | 202.8 | 209.8 | .641 | .495 | 78.1 |
| 300 | 10.73 | 19.02 | 34.36 | 26.34 | 169.1 | 176.2 | .737 | .398 | 55.7 |
| 400 | 8.08 | 19.02 | 34.36 | 26.78 | 127.6 | 135.0 | .893 | .243 | 23.7 |
| 500 | 6.67 | 18.99 | 34.31 | 26.94 | 112.4 | 120.2 | 1.020 | .115 | 5.8 |
| 600 | 5.52 | 18.96 | 34.25 | 27.04 | 102.5 | 110.4 | 1.136 | 0 | 0 |

| STATION | DATE | TIME | LATITUDE | LONGITUDE | D |
|---|---|---|---|---|---|
| H 123 | DEC 14, 1963 | 1800-1845 | 25° 16.0'S | 094° 49.0'W | |

OBSERVED AND COMPUTED VALUES AT OBSERVED DEPTHS

| Z (m) | T (°C) | Cl (‰) | S (‰) | $O_2$ (ml/L) | $\sigma_T$ (gm/L) | $\delta_T$ (cl/L) | AOU (ml/L) | $PO_4$ (µg at./L) | $NO_3$ (µg at./L) | $SiO_4$ (µg at./L) | $NO_2$ (µg at./L) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 0 | 21.80 | 19.68 | 35.55 | 4.97 | 24.71 | 324.0 | -.12 | .28 | .3 | .6 | .03 |
| 25 | 21.07 | 19.64 | 35.48 | 5.08 | 24.86 | 310.1 | -.17 | .21 | 0 | .3 | .03 |
| 50 | 20.00 | 19.61 | 35.43 | 5.23 | 25.11 | 286.7 | -.23 | .20 | 0 | .3 | .02 |
| 74 | 19.47 | 19.59 | 35.39 | 5.19 | 25.22 | 276.1 | -.14 | .18 | 0 | .3 | .02 |
| 99 | 19.12 | 19.56 | 35.34 | 5.31 | 25.27 | 271.4 | -.23 | .22 | 0 | .3 | .02 |
| 148 | 18.37 | 19.53 | 35.28 | 999.00b) | 25.41 | 257.3 | 999.00 | .16 | .1 | .3 | .03 |
| 235 | 16.74 | 19.38 | 35.01 | 5.17 | 25.60 | 239.4 | .15 | .23 | 1.7 | .4 | .20 |
| 328 | 11.02 | 18.98 | 34.29 | 3.67 | 26.24 | 179.0 | 2.34 | 1.24 | 19.2 | 6.6 | .01 |
| 415 | 8.43 | 19.01 | 34.34 | 2.09 | 26.71 | 133.8 | 4.28 | 2.23 | 31.6 | 19.1 | .01 |
| 598 | 5.87 | 18.99 | 34.31 | 3.63 | 27.04 | 102.6 | 3.15 | 1.81 | 34.4 | 21.2 | .01 |

INTERPOLATED AND COMPUTED VALUES AT STANDARD DEPTHS

| Z (m) | T (°C) | Cl (‰) | S (‰) | $\sigma_T$ (gm/L) | $\delta_T$ (cl/T) | $\delta$ (cl/T) | $\Delta D_{Z/0}$ (dyn m) | $\Delta D_{Z/Z\,MAX}$ (dyn m) | $Q_Z$ (m-dynm) |
|---|---|---|---|---|---|---|---|---|---|
| 0 | 21.80 | 19.68 | 35.55 | 24.71 | 324.0 | 324.2 | 0 | 1.224 | 300.6 |
| 10 | 21.62 | 19.67 | 35.53 | 24.75 | 320.5 | 321.0 | .032 | 1.192 | 288.5 |
| 20 | 21.31 | 19.65 | 35.50 | 24.81 | 314.7 | 315.6 | .064 | 1.160 | 276.8 |
| 30 | 20.91 | 19.63 | 35.47 | 24.89 | 306.6 | 307.9 | .095 | 1.129 | 265.3 |
| 50 | 20.00 | 19.61 | 35.43 | 25.10 | 286.7 | 288.6 | .155 | 1.070 | 243.3 |
| 75 | 19.46 | 19.59 | 35.39 | 25.22 | 275.9 | 278.6 | .226 | .999 | 217.5 |
| 100 | 19.11 | 19.56 | 35.33 | 25.27 | 271.2 | 274.7 | .295 | .930 | 193.4 |
| 150 | 18.34 | 19.53 | 35.28 | 25.42 | 256.9 | 262.1 | .429 | .795 | 150.3 |
| 200 | 17.47 | 19.45 | 35.13 | 25.52 | 247.1 | 253.7 | .558 | .666 | 113.7 |
| 250 | 15.94 | 19.31 | 34.89 | 25.69 | 230.5 | 238.3 | .681 | .543 | 83.5 |
| 300 | 12.69 | 19.07 | 34.46 | 26.05 | 196.6 | 204.6 | .792 | .433 | 59.1 |
| 400 | 8.84 | 19.00 | 34.33 | 26.64 | 140.9 | 148.9 | .969 | .256 | 24.6 |
| 500 | 7.12 | 18.99 | 34.31 | 26.88 | 117.9 | 126.2 | 1.106 | .118 | 5.9 |
| 600 | 5.85 | 18.99 | 34.31 | 27.04 | 102.3 | 110.6 | 1.224 | 0 | 0 |

| STATION | DATE | TIME | LATITUDE | LONGITUDE | D |
|---|---|---|---|---|---|
| H 124 | DEC 15, 1963 | 0620-0706 | 24° 36.5' S | 095° 13.1' W | 36 |

OBSERVED AND COMPUTED VALUES AT OBSERVED DEPTHS

| Z (m) | T (°C) | Cl (‰) | S (‰) | $O_2$ (ml/L) | $\sigma_T$ (gm/L) | $\delta_T$ (cl/L) | AOU (ml/L) | $PO_4$ | $NO_3$ (μg at./L) | $SiO_4$ | $NO_2$ |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 0 | 21.20 | 19.61 | 35.43 | 5.01 | 24.78 | 317.4 | -.11 | .23 | .3 | .5 | .03 |
| 25 | 21.00 | 19.60 | 35.41 | 4.99 | 24.82 | 313.5 | -.07 | .19 | .1 | .3 | 0 |
| 49 | 20.38 | 19.59 | 35.39 | 5.12 | 24.98 | 298.9 | -.15 | .19 | .1 | .3 | 0 |
| 74 | 19.53 | 19.57 | 35.35 | 5.21 | 25.17 | 280.2 | -.16 | .24 | .1 | .3 | 0 |
| 99 | 19.11 | 19.55 | 35.32 | 5.17 | 25.25 | 272.5 | -.08 | .22 | .1 | .3 | 0 |
| 148 | 18.35 | 19.48 | 35.19 | 5.19 | 25.35 | 263.4 | -.03 | .19 | .1 | .3 | .01 |
| 216 | 17.43 | 19.40 | 35.05 | 5.07 | 25.47 | 252.4 | .18 | .24 | .9 | .4 | .25 |
| 319 | 11.80 | 18.99 | 34.31 | 4.08 | 26.11 | 191.3 | 1.83 | .96 | 15.4 | 4.1 | .01 |
| 405 | 8.63 | 18.98 | 34.29 | 2.57 | 26.64 | 140.8 | 3.78 | 1.87 | 29.9 | 16.2 | 0 |
| 584 | 5.99 | 18.95 | 34.23 | 3.78 | 26.97 | 109.4 | 2.98 | 1.86 | 33.1 | 19.7 | 0 |

INTERPOLATED AND COMPUTED VALUES AT STANDARD DEPTHS

H 124

| Z (m) | T (°C) | Cl (‰) | S (‰) | $\sigma_T$ (gm/L) | $\delta_T$ (cl/T) | $\delta$ (cl/T) | $\Delta D_{Z/0}$ (dyn m) | $\Delta D_{Z/Z MAX}$ (dyn m) | $Q_Z$ (m-dyn m) |
|---|---|---|---|---|---|---|---|---|---|
| 0 | 21.20 | 19.61 | 35.43 | 24.78 | 317.4 | 317.5 | 0 | 1.251 | 308.5 |
| 10 | 21.15 | 19.61 | 35.42 | 24.79 | 316.4 | 316.9 | .032 | 1.219 | 296.2 |
| 20 | 21.07 | 19.60 | 35.41 | 24.81 | 314.8 | 315.6 | .063 | 1.187 | 284.2 |
| 30 | 20.91 | 19.60 | 35.40 | 24.84 | 311.5 | 312.7 | .095 | 1.156 | 272.4 |
| 50 | 20.35 | 19.59 | 35.39 | 24.98 | 298.3 | 300.2 | .156 | 1.095 | 249.9 |
| 75 | 19.51 | 19.57 | 35.35 | 25.17 | 279.9 | 282.6 | .229 | 1.022 | 223.5 |
| 100 | 19.10 | 19.55 | 35.32 | 25.25 | 272.3 | 275.9 | .299 | .952 | 198.8 |
| 150 | 18.33 | 19.48 | 35.19 | 25.35 | 263.1 | 268.2 | .435 | .816 | 154.6 |
| 200 | 17.67 | 19.42 | 35.08 | 25.44 | 255.1 | 261.8 | .567 | .684 | 117.1 |
| 250 | 15.73 | 19.26 | 34.79 | 25.66 | 233.4 | 241.2 | .693 | .558 | 86.1 |
| 300 | 12.78 | 19.05 | 34.41 | 25.99 | 202.0 | 209.9 | .806 | .445 | 61.0 |
| 400 | 8.80 | 18.98 | 34.29 | 26.61 | 143.4 | 151.4 | .986 | .264 | 25.5 |
| 500 | 7.11 | 18.96 | 34.25 | 26.83 | 122.7 | 131.0 | 1.128 | .123 | 6.2 |
| 600 | 5.79 | 18.95 | 34.23 | 26.99 | 107.1 | 115.4 | 1.251 | 0 | 0 |

| STATION | DATE | TIME | LATITUDE | LONGITUDE | D |
|---|---|---|---|---|---|
| H 125 | DEC 15, 1963 | 2210-2250 | 23° 30.2' S | 095° 02.3' W | |

OBSERVED AND COMPUTED VALUES AT OBSERVED DEPTHS

| Z (m) | T (°C) | Cl (‰) | S (‰) | $O_2$ (ml/L) | $\sigma_T$ (gm/L) | $\delta_T$ (cl/L) | AOU (ml/L) | $PO_4$ | $NO_3$ (μg at./L) | $SiO_4$ | $NO_2$ |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 0 | 21.30 | 999.00 C) | 999.00 | 4.96 | 999.00 | 999.0 | 999.00 | .27 | .2 | .6 | .02 |
| 25 | 21.13 | 999.00 | 999.00 | 5.00 | 999.00 | 999.0 | 999.00 | .30 | .1 | .3 | 0 |
| 49 | 21.07 | 999.00 | 999.00 | 4.95 | 999.00 | 999.0 | 999.00 | .29 | .1 | .4 | 0 |
| 74 | 20.95 | 999.00 | 999.00 | 5.00 | 999.00 | 999.0 | 999.00 | .30 | 0 | .3 | 0 |
| 99 | 19.54 | 999.00 | 999.00 | 5.18 | 999.00 | 999.0 | 999.00 | .30 | .1 | .3 | 0 |
| 148 | 17.57 | 999.00 | 999.00 | 4.97 | 999.00 | 999.0 | 999.00 | .25 | 1.1 | .4 | .08 |
| 212 | 13.94 | 999.00 | 999.00 | 4.39 | 999.00 | 999.0 | 999.00 | .70 | 10.1 | 1.9 | .02 |
| 300 | 10.25 | 999.00 | 999.00 | 1.76 | 999.00 | 999.0 | 999.00 | 2.33 | 27.6 | 18.4 | 0 |
| 395 | 8.25 | 999.00 | 999.00 | 1.70 | 999.00 | 999.0 | 999.00 | 2.54 | 34.3 | 22.6 | 0 |
| 562 | 5.74 | 999.00 | 999.00 | 3.71 | 999.00 | 999.0 | 999.00 | 2.22 | 34.0 | 22.7 | 0 |

H 125

INTERPOLATED AND COMPUTED VALUES AT STANDARD DEPTHS

| Z (m) | T (°C) | Cl (‰) | S (‰) | $\sigma_T$ (gm/L) | $\delta_T$ (cl/T) | $\delta$ (cl/T) | $\Delta D_{Z/0}$ (dyn m) | $\Delta D_{Z/Z MAX}$ (dyn m) | $Q_Z$ (m-dyn m) |
|---|---|---|---|---|---|---|---|---|---|
| 0 | 21.30 | | | | | | | | |
| 10 | 21.26 | | | | | | | | |
| 20 | 21.19 | | | | | | | | |
| 30 | 21.12 | | | | | | | | |
| 50 | 21.07 | | | | | | | | |
| 75 | 20.92 | | | | | | | | |
| 100 | 19.51 | | | | | | | | |
| 150 | 17.47 | | | | | | | | |
| 200 | 14.59 | | | | | | | | |
| 250 | 12.19 | | | | | | | | |
| 300 | 10.25 | | | | | | | | |
| 400 | 8.16 | | | | | | | | |
| 500 | 6.57 | | | | | | | | |
| 600 | 5.27 | | | | | | | | |

| STATION | DATE | TIME | LATITUDE | LONGITUDE | D |
|---|---|---|---|---|---|
| H 126 | DEC 16, 1963 | 0600-0642 | 22° 11.6'S | 095° 04.8'W | |

OBSERVED AND COMPUTED VALUES AT OBSERVED DEPTHS

| Z (m) | T (°C) | Cl (‰) | S (‰) | $O_2$ (ml/L) | $\sigma_T$ (gm/L) | $\delta_T$ (cl/L) | AOU (ml/L) | $PO_4$ (µg at./L) | $NO_3$ (µg at./L) | $SiO_4$ (µg at./L) | $NO_2$ (µg at./L) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 0 | 21.20 | 19.71 | 35.61 | 4.99 | 24.92 | 304.3 | -.10 | .22 | .5 | .7 | .03 |
| 49 | 20.41 | 19.63 | 35.46 | 5.14 | 25.02 | 294.4 | -.17 | .22 | .1 | .4 | .03 |
| 73 | 19.42 | 19.60 | 35.41 | 5.05 | 25.24 | 273.5 | .01 | .22 | 0 | .5 | 0 |
| 98 | 18.99 | 19.59 | 35.39 | 5.07 | 25.34 | 264.3 | .02 | .23 | 0 | .6 | 0 |
| 147 | 17.76 | 19.54 | 35.30 | 5.37 | 25.58 | 241.6 | -.16 | .18 | .4 | .6 | .03 |
| 216 | 14.87 | 19.23 | 34.74 | 4.70 | 25.82 | 218.8 | .83 | .51 | 7.3 | 1.2 | .03 |
| 305 | 9.93 | 19.10 | 34.51 | 2.49 | 26.60 | 144.8 | 3.66 | 1.56 | 26.4 | 14.6 | 0 |
| 396 | 8.64 | 19.16 | 34.61 | 1.01 | 26.89 | 116.8 | 5.32 | 2.19 | 35.6 | 26.4 | 0 |
| 570 | 5.80 | 19.08 | 34.47 | 3.16 | 27.18 | 89.6 | 3.62 | 1.88 | 35.6 | 26.6 | .01 |

INTERPOLATED AND COMPUTED VALUES AT STANDARD DEPTHS

| Z (m) | T (°C) | Cl (‰) | S (‰) | $\sigma_T$ (gm/L) | $\delta_T$ (cl/T) | $\delta$ (cl/T) | $\Delta D_{Z/0}$ (dyn m) | $\Delta D_{Z/Z\,MAX}$ (dyn m) | $Q_Z$ (m-dynm) |
|---|---|---|---|---|---|---|---|---|---|
| 0 | 21.20 | 19.71 | 35.61 | 24.92 | 304.3 | 304.4 | 0 | 1.089 | 255.7 |
| 10 | 21.11 | 19.70 | 35.59 | 24.93 | 303.2 | 303.7 | .030 | 1.059 | 245.0 |
| 20 | 21.00 | 19.69 | 35.57 | 24.95 | 301.8 | 302.6 | .061 | 1.028 | 234.5 |
| 30 | 20.85 | 19.67 | 35.54 | 24.96 | 300.0 | 301.2 | .091 | .998 | 224.4 |
| 50 | 20.38 | 19.63 | 35.46 | 25.03 | 293.8 | 295.7 | .151 | .938 | 205.0 |
| 75 | 19.39 | 19.60 | 35.41 | 25.25 | 272.9 | 275.6 | .222 | .867 | 182.5 |
| 100 | 18.95 | 19.59 | 35.39 | 25.35 | 263.6 | 267.1 | .290 | .799 | 161.7 |
| 150 | 17.66 | 19.53 | 35.28 | 25.59 | 240.8 | 245.8 | .418 | .671 | 124.9 |
| 200 | 15.68 | 19.32 | 34.89 | 25.76 | 224.7 | 230.9 | .537 | .552 | 94.4 |
| 250 | 13.05 | 19.16 | 34.62 | 26.10 | 191.7 | 198.5 | .645 | .444 | 69.5 |
| 300 | 10.19 | 19.10 | 34.51 | 26.56 | 148.7 | 155.5 | .733 | .356 | 49.5 |
| 400 | 8.56 | 19.16 | 34.61 | 26.90 | 116.1 | 123.9 | .873 | .216 | 20.9 |
| 500 | 6.82 | 19.10 | 34.51 | 27.08 | 99.4 | 107.4 | .988 | .100 | 5.0 |
| 600 | 5.40 | 19.07 | 34.46 | 27.22 | 85.8 | 93.6 | 1.089 | 0 | 0 |

H 12

| STATION | DATE | TIME | LATITUDE | LONGITUDE | D |
|---|---|---|---|---|---|
| H 127 | DEC 16, 1963 | 1200-1238 | 21° 15.8'S | 095° 01.9'W | 30 |

OBSERVED AND COMPUTED VALUES AT OBSERVED DEPTHS

| Z (m) | T (°C) | Cl (‰) | S (‰) | $O_2$ (ml/L) | $\sigma_T$ (gm/L) | $\delta_T$ (cl/L) | AOU (ml/L) | $PO_4$ (µg at./L) | $NO_3$ (µg at./L) | $SiO_4$ (µg at./L) | $NO_2$ (µg at./L) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 0 | 21.90 | 19.87 | 35.90 | 4.97 | 24.94 | 301.9 | -.14 | .27 | .3 | .6 | .03 |
| 50 | 21.49 | 19.87 | 35.90 | 4.93 | 25.06 | 291.0 | -.07 | .26 | 0 | .4 | .01 |
| 75 | 21.10 | 19.81 | 35.79 | 4.96 | 25.08 | 288.7 | -.06 | .23 | 0 | .3 | 0 |
| 100 | 20.76 | 19.81 | 35.79 | 5.17 | 25.18 | 279.9 | -.24 | .24 | 0 | .4 | 0 |
| 149 | 18.85 | 19.61 | 35.43 | 5.16 | 25.40 | 258.3 | -.05 | .21 | .2 | .3 | .03 |
| 200 | 17.18 | 19.43 | 35.10 | 4.88 | 25.57 | 242.7 | .40 | .26 | 2.0 | .4 | .16 |
| 293 | 10.96 | 19.08 | 34.47 | 3.46 | 26.39 | 164.6 | 2.55 | 1.32 | 20.4 | 7.8 | .01 |
| 389 | 8.46 | 19.10 | 34.51 | 1.82 | 26.84 | 122.2 | 4.54 | 2.12 | 33.6 | 21.4 | 0 |
| 572 | 5.76 | 19.06 | 34.43 | 3.40 | 27.16 | 91.8 | 3.39 | 2.22 | 35.8 | 24.4 | .01 |

H 12

INTERPOLATED AND COMPUTED VALUES AT STANDARD DEPTHS

| Z (m) | T (°C) | Cl (‰) | S (‰) | $\sigma_T$ (gm/L) | $\delta_T$ (cl/T) | $\delta$ (cl/T) | $\Delta D_{Z/0}$ (dyn m) | $\Delta D_{Z/Z\,MAX}$ (dyn m) | $Q_Z$ (m-dynm) |
|---|---|---|---|---|---|---|---|---|---|
| 0 | 21.90 | 19.87 | 35.89 | 24.94 | 301.9 | 302.0 | 0 | 1.137 | 267.6 |
| 10 | 21.85 | 19.87 | 35.89 | 24.96 | 300.7 | 301.2 | .030 | 1.107 | 256.4 |
| 20 | 21.80 | 19.87 | 35.89 | 24.97 | 299.2 | 300.1 | .060 | 1.077 | 245.5 |
| 30 | 21.72 | 19.87 | 35.89 | 24.99 | 297.3 | 298.5 | .090 | 1.047 | 234.8 |
| 50 | 21.49 | 19.87 | 35.89 | 25.06 | 291.0 | 293.0 | .149 | .988 | 214.5 |
| 75 | 21.10 | 19.81 | 35.79 | 25.08 | 288.7 | 291.5 | .222 | .915 | 190.7 |
| 100 | 20.76 | 19.81 | 35.79 | 25.18 | 279.9 | 283.6 | .294 | .843 | 168.7 |
| 150 | 18.82 | 19.61 | 35.42 | 25.40 | 258.0 | 263.3 | .431 | .706 | 130.0 |
| 200 | 17.18 | 19.43 | 35.10 | 25.57 | 242.7 | 249.3 | .559 | .578 | 97.9 |
| 250 | 13.82 | 19.21 | 34.70 | 26.01 | 200.5 | 207.6 | .673 | .464 | 71.9 |
| 300 | 10.75 | 19.08 | 34.47 | 26.43 | 161.1 | 168.1 | .767 | .370 | 51.0 |
| 400 | 8.26 | 19.09 | 34.50 | 26.86 | 120.0 | 127.6 | .915 | .222 | 21.4 |
| 500 | 6.70 | 19.07 | 34.45 | 27.04 | 102.4 | 110.3 | 1.034 | .103 | 5.2 |
| 600 | 5.43 | 19.06 | 34.43 | 27.20 | 88.1 | 95.9 | 1.137 | 0 | 0 |

| STATION | DATE | TIME | LATITUDE | LONGITUDE | D |
|---|---|---|---|---|---|
| H 128 | DEC 16, 1963 | 1800-1838 | 20° 18.6'S | 094° 57.8'W | |

OBSERVED AND COMPUTED VALUES AT OBSERVED DEPTHS

| Z (m) | T (°C) | Cl (‰) | S (‰) | $O_2$ (ml/L) | $\sigma_T$ (gm/L) | $\delta_T$ (cl/L) | AOU (ml/L) | $PO_4$ (µg at./L) | $NO_3$ (µg at./L) | $SiO_4$ (µg at./L) | $NO_2$ (µg at./L) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 0 | 21.80 | 19.84 | 35.84 | 4.96 | 24.93 | 303.2 | -.12 | .34 | .2 | .6 | 0 |
| 47 | 21.35 | 19.84 | 35.84 | 5.04 | 25.06 | 291.3 | -.17 | .34 | 0 | .5 | .01 |
| 70 | 21.03 | 19.83 | 35.82 | 4.98 | 25.13 | 284.2 | -.08 | .32 | 0 | .4 | 0 |
| 94 | 20.12 | 19.68 | 35.55 | 5.00 | 25.17 | 280.5 | -.01 | .35 | 0 | .7 | .01 |
| 141 | 19.57 | 19.73 | 35.64 | 4.90 | 25.38 | 260.2 | .13 | .42 | 1.3 | .7 | .27 |
| 225 | 15.32 | 19.27 | 34.81 | 4.49 | 25.78 | 223.0 | .99 | .49 | 7.1 | 1.2 | .02 |
| 318 | 10.62 | 19.16 | 34.61 | 1.25 | 26.56 | 148.2 | 4.80 | 2.29 | 28.2 | 22.0 | 0 |
| 413 | 8.64 | 19.13 | 34.56 | 1.13 | 26.85 | 120.9 | 5.20 | 2.46 | 34.9 | 25.4 | .01 |
| 601 | 5.96 | 19.08 | 34.47 | 2.51 | 27.16 | 91.5 | 4.24 | 2.21 | 39.1 | 31.8 | .01 |

INTERPOLATED AND COMPUTED VALUES AT STANDARD DEPTHS

| Z (m) | T (°C) | Cl (‰) | S (‰) | $\sigma_T$ (gm/L) | $\delta_T$ (cl/T) | $\delta$ (cl/T) | $\Delta D_{Z/0}$ (dyn m) | $\Delta D_{Z/Z\,MAX}$ (dyn m) | $Q_Z$ (m-dyn m) |
|---|---|---|---|---|---|---|---|---|---|
| 0 | 21.80 | 19.84 | 35.84 | 24.93 | 303.2 | 303.3 | 0 | 1.141 | 271.4 |
| 10 | 21.75 | 19.84 | 35.84 | 24.95 | 301.8 | 302.2 | .030 | 1.111 | 260.2 |
| 20 | 21.68 | 19.84 | 35.84 | 24.96 | 300.0 | 300.8 | .060 | 1.080 | 249.2 |
| 30 | 21.59 | 19.84 | 35.84 | 24.99 | 297.6 | 298.8 | .090 | 1.051 | 238.6 |
| 50 | 21.32 | 19.84 | 35.84 | 25.06 | 290.5 | 292.5 | .150 | .991 | 218.2 |
| 75 | 20.88 | 19.81 | 35.78 | 25.14 | 283.5 | 286.3 | .222 | .919 | 194.3 |
| 100 | 20.06 | 19.68 | 35.56 | 25.19 | 278.5 | 282.1 | .293 | .848 | 172.2 |
| 150 | 19.21 | 19.69 | 35.57 | 25.42 | 256.7 | 262.0 | .429 | .712 | 133.2 |
| 200 | 16.53 | 19.39 | 35.03 | 25.66 | 233.6 | 240.0 | .554 | .586 | 100.7 |
| 250 | 13.89 | 19.22 | 34.72 | 26.01 | 200.2 | 207.3 | .666 | .475 | 74.2 |
| 300 | 11.41 | 19.17 | 34.63 | 26.43 | 160.8 | 168.2 | .760 | .381 | 52.8 |
| 400 | 8.88 | 19.13 | 34.56 | 26.81 | 124.2 | 132.2 | .910 | .231 | 22.3 |
| 500 | 7.27 | 19.10 | 34.50 | 27.01 | 105.9 | 114.4 | 1.034 | .107 | 5.4 |
| 600 | 5.97 | 19.08 | 34.47 | 27.16 | 91.6 | 100.2 | 1.141 | 0 | 0 |

H 128

| STATION | DATE | TIME | LATITUDE | LONGITUDE | D |
|---|---|---|---|---|---|
| H 129 | DEC 17, 1963 | 0602-0658 | 19° 43.0'S | 095° 17.0'W | 20 |

OBSERVED AND COMPUTED VALUES AT OBSERVED DEPTHS

| Z (m) | T (°C) | Cl (‰) | S (‰) | $O_2$ (ml/L) | $\sigma_T$ (gm/L) | $\delta_T$ (cl/L) | AOU (ml/L) | $PO_4$ (µg at./L) | $NO_3$ (µg at./L) | $SiO_4$ (µg at./L) | $NO_2$ (µg at./L) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 0 | 21.80 | 19.89 | 35.93 | 4.89 | 25.00 | 296.6 | -.06 | .34 | .5 | .6 | .06 |
| 50 | 21.33 | 19.77 | 35.71 | 4.96 | 24.97 | 299.9 | -.08 | .35 | 0 | .4 | .01 |
| 74 | 20.93 | 19.87 | 35.90 | 4.93 | 25.21 | 276.4 | -.02 | .34 | .4 | .4 | .02 |
| 99 | 21.10 | 19.86 | 35.88 | 4.82 | 25.15 | 282.1 | .07 | .36 | .7 | .5 | .08 |
| 148 | 19.64 | 19.80 | 35.77 | 4.95 | 25.46 | 252.8 | .07 | .35 | .6 | .4 | .19 |
| 197 | 17.59 | 19.72 | 35.62 | 4.01 | 25.87 | 214.1 | 1.21 | .83 | 10.6 | 2.0 | .05 |
| 294 | 11.15 | 19.53 | 35.28 | 1.80 | 26.99 | 108.0 | 4.16 | 1.73 | 25.2 | 16.2 | .01 |
| 387 | 9.66 | 19.16 | 34.61 | .47 | 26.73 | 132.5 | 5.71 | 2.75 | 36.5 | 29.1 | 0 |
| 570 | 6.46 | 19.19 | 34.67 | 1.77 | 27.25 | 82.8 | 4.89 | 2.27 | 40.8 | 34.4 | 0 |

H 129

INTERPOLATED AND COMPUTED VALUES AT STANDARD DEPTHS

| Z (m) | T (°C) | Cl (‰) | S (‰) | $\sigma_T$ (gm/L) | $\delta_T$ (cl/T) | $\delta$ (cl/T) | $\Delta D_{Z/0}$ (dyn m) | $\Delta D_{Z/Z\,MAX}$ (dyn m) | $Q_Z$ (m-dyn m) |
|---|---|---|---|---|---|---|---|---|---|
| 0 | 21.80 | 19.89 | 35.93 | 25.00 | 296.6 | 296.8 | 0 | 1.059 | 245.5 |
| 10 | 21.75 | 19.86 | 35.88 | 24.98 | 298.6 | 299.1 | .030 | 1.029 | 235.1 |
| 20 | 21.68 | 19.85 | 35.85 | 24.97 | 299.2 | 300.0 | .060 | .999 | 225.0 |
| 30 | 21.60 | 19.83 | 35.82 | 24.97 | 299.5 | 300.7 | .090 | .969 | 215.1 |
| 50 | 21.33 | 19.77 | 35.71 | 24.96 | 299.9 | 301.8 | .150 | .909 | 196.3 |
| 75 | 20.94 | 19.87 | 35.89 | 25.21 | 276.7 | 279.5 | .223 | .836 | 174.5 |
| 100 | 21.08 | 19.86 | 35.88 | 25.16 | 281.7 | 285.4 | .293 | .765 | 154.5 |
| 150 | 19.58 | 19.80 | 35.76 | 25.47 | 251.5 | 256.8 | .429 | .630 | 119.6 |
| 200 | 17.43 | 19.71 | 35.61 | 25.90 | 211.3 | 217.9 | .548 | .511 | 91.1 |
| 250 | 14.05 | 19.58 | 35.37 | 26.48 | 155.7 | 162.9 | .643 | .416 | 67.9 |
| 300 | 11.04 | 19.50 | 35.23 | 26.97 | 109.8 | 117.0 | .713 | .346 | 48.9 |
| 400 | 9.39 | 19.16 | 34.61 | 26.77 | 128.3 | 136.7 | .840 | .219 | 20.6 |
| 500 | 7.54 | 19.17 | 34.63 | 27.07 | 99.6 | 108.4 | .962 | .097 | 4.8 |
| 600 | 6.04 | 19.20 | 34.69 | 27.32 | 76.3 | 84.9 | 1.059 | 0 | 0 |

| STATION | DATE | TIME | LATITUDE | LONGITUDE | D |
|---|---|---|---|---|---|
| H 130 | DEC 17, 1963 | 2210-2249 | 18° 45.8'S | 095° 00.3'W | |

OBSERVED AND COMPUTED VALUES AT OBSERVED DEPTHS

| Z (m) | T (°C) | Cl (‰) | S (‰) | $O_2$ (ml/L) | $\sigma_T$ (gm/L) | $\delta_T$ (cl/L) | AOU (ml/L) | $PO_4$ | $NO_3$ | $SiO_4$ | $NO_2$ |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | —— (µg at./L) —— | | | |
| 0 | 21.50 | 19.82 | 35.81 | 5.02 | 24.99 | 297.8 | -.16 | .34 | .4 | .8 | .05 |
| 49 | 21.28 | 19.88 | 35.91 | 5.01 | 25.13 | 284.2 | -.13 | .30 | 0 | .6 | 0 |
| 74 | 21.17 | 19.83 | 35.82 | 4.96 | 25.09 | 287.9 | -.07 | .30 | .2 | .5 | .01 |
| 99 | 20.56 | 19.78 | 35.73 | 4.84 | 25.19 | 278.6 | .10 | .44 | 1.4 | 1.1 | .08 |
| 148 | 19.98 | 19.77 | 35.71 | 4.90 | 25.33 | 265.2 | .10 | .37 | 1.0 | .7 | .23 |
| 200 | 17.10 | 19.45 | 35.14 | 4.44 | 25.61 | 238.3 | .84 | .53 | 5.9 | 1.1 | .04 |
| 297 | 11.26 | 19.18 | 34.65 | 1.93 | 26.47 | 156.5 | 4.04 | 1.90 | 24.8 | 15.2 | 0 |
| 393 | 9.02 | 19.17 | 34.63 | .59 | 26.85 | 121.2 | 5.68 | 2.27 | 37.8 | 28.9 | 0 |
| 572 | 6.63 | 19.17 | 34.63 | 1.34 | 27.20 | 87.7 | 5.30 | 2.52 | 41.8 | 39.0 | 0 |

INTERPOLATED AND COMPUTED VALUES AT STANDARD DEPTHS

| Z (m) | T (°C) | Cl (‰) | S (‰) | $\sigma_T$ (gm/L) | $\delta_T$ (cl/T) | $\delta$ (cl/T) | $\Delta D_{Z/0}$ (dyn m) | $\Delta D_{Z/Z\,MAX}$ (dyn m) | $Q_Z$ (m-dynm) |
|---|---|---|---|---|---|---|---|---|---|
| 0 | 21.50 | 19.82 | 35.80 | 24.99 | 297.8 | 298.0 | 0 | 1.124 | 263.6 |
| 10 | 21.48 | 19.83 | 35.82 | 25.00 | 296.3 | 296.8 | .030 | 1.094 | 252.5 |
| 20 | 21.44 | 19.84 | 35.83 | 25.02 | 294.3 | 295.2 | .059 | 1.065 | 241.7 |
| 30 | 21.40 | 19.85 | 35.85 | 25.05 | 291.8 | 293.1 | .089 | 1.035 | 231.2 |
| 50 | 21.28 | 19.88 | 35.91 | 25.13 | 284.4 | 286.3 | .147 | .977 | 211.1 |
| 75 | 21.15 | 19.83 | 35.82 | 25.09 | 287.6 | 290.4 | .219 | .905 | 187.6 |
| 100 | 20.55 | 19.78 | 35.73 | 25.19 | 278.4 | 282.1 | .290 | .834 | 165.9 |
| 150 | 19.90 | 19.76 | 35.70 | 25.34 | 264.4 | 269.8 | .428 | .696 | 127.6 |
| 200 | 17.10 | 19.45 | 35.14 | 25.61 | 238.3 | 244.8 | .557 | .567 | 96.1 |
| 250 | 14.08 | 19.28 | 34.83 | 26.06 | 196.0 | 203.2 | .669 | .455 | 70.5 |
| 300 | 11.18 | 19.18 | 34.65 | 26.49 | 155.2 | 162.5 | .760 | .364 | 50.1 |
| 400 | 8.91 | 19.17 | 34.63 | 26.86 | 119.6 | 127.7 | .906 | .218 | 21.0 |
| 500 | 7.49 | 19.16 | 34.62 | 27.07 | 99.7 | 108.4 | 1.024 | .100 | 5.0 |
| 600 | 6.33 | 19.17 | 34.64 | 27.24 | 83.4 | 92.4 | 1.124 | 0 | 0 |

| STATION | DATE | TIME | LATITUDE | LONGITUDE | D |
|---|---|---|---|---|---|
| H 131 | DEC 18, 1963 | 0600-0640 | 17° 29.2'S | 095° 00.3'W | 25 |

OBSERVED AND COMPUTED VALUES AT OBSERVED DEPTHS

| Z (m) | T (°C) | Cl (‰) | S (‰) | $O_2$ (ml/L) | $\sigma_T$ (gm/L) | $\delta_T$ (cl/L) | AOU (ml/L) | $PO_4$ | $NO_3$ | $SiO_4$ | $NO_2$ |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | —— (µg at./L) —— | | | |
| 0 | 21.70 | 19.98 | 36.09 | 4.99 | 25.15 | 282.3 | -.15 | .37 | .7 | 1.1 | .03 |
| 50 | 21.41 | 19.83 | 35.82 | 5.01 | 25.03 | 294.2 | -.14 | .33 | .5 | .7 | .02 |
| 74 | 21.12 | 19.80 | 35.77 | 4.93 | 25.06 | 290.5 | -.03 | .39 | .4 | .8 | .02 |
| 99 | 20.52 | 19.76 | 35.70 | 4.91 | 25.17 | 280.2 | .04 | .35 | .6 | .7 | .05 |
| 149 | 19.97 | 19.74 | 35.66 | 4.83 | 25.29 | 268.9 | .17 | .38 | 1.4 | .6 | .40 |
| 220 | 14.60 | 19.28 | 34.83 | 3.44 | 25.95 | 206.7 | 2.12 | 1.08 | 15.7 | 4.5 | .02 |
| 315 | 10.27 | 19.19 | 34.67 | .82 | 26.67 | 138.4 | 5.28 | 2.14 | 31.3 | 24.6 | .01 |
| 411 | 8.19 | 19.17 | 34.63 | 1.08 | 26.98 | 108.9 | 5.32 | 2.32 | 37.0 | 28.0 | .01 |
| 597 | 6.09 | 19.13 | 34.56 | 1.42 | 27.21 | 86.3 | 5.31 | -0 | -0 | -0 | -0 |

INTERPOLATED AND COMPUTED VALUES AT STANDARD DEPTHS

| Z (m) | T (°C) | Cl (‰) | S (‰) | $\sigma_T$ (gm/L) | $\delta_T$ (cl/T) | $\delta$ (cl/T) | $\Delta D_{Z/0}$ (dyn m) | $\Delta D_{Z/Z\,MAX}$ (dyn m) | $Q_Z$ (m-dynm) |
|---|---|---|---|---|---|---|---|---|---|
| 0 | 21.70 | 19.98 | 36.09 | 25.15 | 282.3 | 282.4 | 0 | 1.097 | 254.9 |
| 10 | 21.67 | 19.92 | 35.98 | 25.07 | 289.5 | 290.0 | .029 | 1.069 | 244.0 |
| 20 | 21.63 | 19.89 | 35.94 | 25.05 | 291.5 | 292.3 | .058 | 1.040 | 233.5 |
| 30 | 21.58 | 19.87 | 35.90 | 25.04 | 292.7 | 293.9 | .087 | 1.010 | 223.2 |
| 50 | 21.41 | 19.83 | 35.82 | 25.03 | 294.2 | 296.1 | .146 | .951 | 203.6 |
| 75 | 21.10 | 19.80 | 35.77 | 25.07 | 290.2 | 293.0 | .220 | .878 | 180.8 |
| 100 | 20.51 | 19.76 | 35.70 | 25.17 | 280.0 | 283.7 | .292 | .806 | 159.7 |
| 150 | 19.92 | 19.73 | 35.65 | 25.30 | 268.3 | 273.6 | .431 | .666 | 122.9 |
| 200 | 16.05 | 19.39 | 35.02 | 25.77 | 223.5 | 229.8 | .557 | .540 | 92.8 |
| 250 | 13.06 | 19.23 | 34.74 | 26.20 | 182.3 | 189.2 | .662 | .436 | 68.4 |
| 300 | 10.86 | 19.19 | 34.68 | 26.57 | 147.7 | 154.8 | .748 | .350 | 48.7 |
| 400 | 8.40 | 19.17 | 34.63 | 26.94 | 111.9 | 119.6 | .885 | .212 | 20.6 |
| 500 | 7.09 | 19.14 | 34.59 | 27.10 | 97.1 | 105.3 | .997 | .100 | 5.0 |
| 600 | 6.06 | 19.13 | 34.56 | 27.22 | 86.0 | 94.7 | 1.097 | 0 | 0 |

| STATION | DATE | TIME | LATITUDE | LONGITUDE | D |
|---|---|---|---|---|---|
| H 132 | DEC 18, 1963 | 1205-1235 | 16° 29.8'S | 095° 03.1'W | 20 |

OBSERVED AND COMPUTED VALUES AT OBSERVED DEPTHS

| Z (m) | T (°C) | Cl (‰) | S (‰) | $O_2$ (ml/L) | $\sigma_T$ (gm/L) | $\delta_T$ (cl/L) | AOU (ml/L) | $PO_4$ (μg at./L) | $NO_3$ (μg at./L) | $SiO_4$ (μg at./L) | $NO_2$ (μg at./L) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 0 | 21.80 | 999.00d) | 999.00 | 4.98 | 999.00 | 999.0 | 999.00 | .45 | .5 | .8 | .02 |
| 49 | 21.41 | 999.00 | 999.00 | 5.00 | 999.00 | 999.0 | 999.00 | .35 | .3 | .5 | .02 |
| 73 | 21.15 | 999.00 | 999.00 | 5.02 | 999.00 | 999.0 | 999.00 | .36 | .3 | .5 | .02 |
| 98 | 19.83 | 999.00 | 999.00 | 4.90 | 999.00 | 999.0 | 999.00 | .38 | .4 | .5 | .04 |
| 147 | 15.78 | 999.00 | 999.00 | 5.04 | 999.00 | 999.0 | 999.00 | .36 | 2.0 | .5 | .46 |
| 200 | 14.74 | 999.00 | 999.00 | 3.93 | 999.00 | 999.0 | 999.00 | .82 | 12.0 | 2.7 | .02 |
| 295 | 10.03 | 999.00 | 999.00 | 999.00e) | 999.00 | 999.0 | 999.00 | 1.42 | 19.8 | 13.1 | .03 |
| 383 | 8.26 | 999.00 | 999.00 | .86 | 999.00 | 999.0 | 999.00 | 2.39 | 40.0 | 30.8 | .01 |
| 575 | 6.39 | 999.00 | 999.00 | 1.17 | 999.00 | 999.0 | 999.00 | 2.34 | 38.1 | 33.6 | .01 |

INTERPOLATED AND COMPUTED VALUES AT STANDARD DEPTHS

H 132

| Z (m) | T (°C) | Cl (‰) | S (‰) | $\sigma_T$ (gm/L) | $\delta_T$ (cl/T) | $\delta$ (cl/T) | $\Delta D_{Z/0}$ (dyn m) | $\Delta D_{Z/Z\,MAX}$ (dyn m) | $Q_Z$ (m-dynm) |
|---|---|---|---|---|---|---|---|---|---|
| 0 | 21.80 | | | | | | | | |
| 10 | 21.76 | | | | | | | | |
| 20 | 21.70 | | | | | | | | |
| 30 | 21.63 | | | | | | | | |
| 50 | 21.40 | | | | | | | | |
| 75 | 21.08 | | | | | | | | |
| 100 | 19.70 | | | | | | | | |
| 150 | 15.71 | | | | | | | | |
| 200 | 14.74 | | | | | | | | |
| 250 | 12.04 | | | | | | | | |
| 300 | 9.92 | | | | | | | | |
| 400 | 8.06 | | | | | | | | |
| 500 | 7.03 | | | | | | | | |
| 600 | 6.19 | | | | | | | | |

| STATION | DATE | TIME | LATITUDE | LONGITUDE | D |
|---|---|---|---|---|---|
| H 133 | DEC 18, 1963 | 1800-1835 | 15° 30.8'S | 095° 03.2'W | |

OBSERVED AND COMPUTED VALUES AT OBSERVED DEPTHS

| Z (m) | T (°C) | Cl (‰) | S (‰) | $O_2$ (ml/L) | $\sigma_T$ (gm/L) | $\delta_T$ (cl/L) | AOU (ml/L) | $PO_4$ (μg at./L) | $NO_3$ (μg at./L) | $SiO_4$ (μg at./L) | $NO_2$ (μg at./L) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 0 | 22.00 | 19.88 | 35.91 | 4.93 | 24.93 | 303.3 | -.11 | .37 | .6 | .7 | .03 |
| 50 | 21.65 | 19.86 | 35.88 | 4.95 | 25.00 | 296.6 | -.10 | .34 | .4 | .4 | .02 |
| 75 | 21.62 | 19.89 | 35.93 | 4.91 | 25.05 | 291.9 | -.06 | .39 | .4 | .5 | .02 |
| 100 | 20.51 | 999.00 | 999.00 | 4.88 | 999.00 | 999.0 | 999.00 | .40 | .8 | 1.1 | .06 |
| 150 | 19.98 | 19.70 | 35.59 | 4.87 | 25.23 | 274.4 | .13 | .33 | .6 | .5 | .20 |
| 200 | 16.12 | 19.39 | 35.03 | 3.88 | 25.76 | 224.3 | 1.51 | .67 | 11.9 | 2.4 | .02 |
| 295 | 10.63 | 19.20 | 34.69 | .81 | 26.62 | 143.0 | 5.24 | 2.12 | 31.0 | 23.2 | 0 |
| 385 | 8.81 | 19.20 | 34.69 | .68 | 26.92 | 114.0 | 5.62 | 2.71 | 38.1 | 31.8 | 0 |
| 576 | 6.70 | 19.14 | 34.58 | .90 | 27.15 | 92.6 | 5.73 | -0 | -0 | -0 | -0 |

H 133

INTERPOLATED AND COMPUTED VALUES AT STANDARD DEPTHS

| Z (m) | T (°C) | Cl (‰) | S (‰) | $\sigma_T$ (gm/L) | $\delta_T$ (cl/T) | $\delta$ (cl/T) | $\Delta D_{Z/0}$ (dyn m) | $\Delta D_{Z/Z\,MAX}$ (dyn m) | $Q_Z$ (m-dynm) |
|---|---|---|---|---|---|---|---|---|---|
| 0 | 22.00 | 19.88 | 35.91 | 24.93 | 303.3 | 303.4 | 0 | 1.108 | 256.8 |
| 10 | 21.96 | 19.88 | 35.91 | 24.94 | 302.5 | 303.0 | .030 | 1.078 | 245.9 |
| 20 | 21.91 | 19.87 | 35.90 | 24.95 | 301.6 | 302.5 | .061 | 1.047 | 235.3 |
| 30 | 21.85 | 19.87 | 35.90 | 24.96 | 300.4 | 301.6 | .091 | 1.017 | 224.9 |
| 50 | 21.65 | 19.86 | 35.88 | 25.00 | 296.6 | 298.5 | .151 | .957 | 205.2 |
| 75 | 21.62 | 19.89 | 35.93 | 25.05 | 291.9 | 294.8 | .225 | .883 | 182.2 |
| 100 | 20.51 | 19.70 | 35.59 | 25.10 | 287.4 | 291.0 | .298 | .810 | 161.0 |
| 150 | 19.98 | 19.70 | 35.59 | 25.23 | 274.4 | 279.8 | .441 | .667 | 124.1 |
| 200 | 16.12 | 19.39 | 35.03 | 25.76 | 224.3 | 230.6 | .569 | .539 | 94.0 |
| 250 | 12.97 | 19.25 | 34.79 | 26.25 | 177.7 | 184.5 | .672 | .436 | 69.6 |
| 300 | 10.52 | 19.20 | 34.68 | 26.63 | 141.2 | 148.1 | .755 | .352 | 49.9 |
| 400 | 8.61 | 19.19 | 34.67 | 26.94 | 112.0 | 119.8 | .889 | .218 | 21.3 |
| 500 | 7.44 | 19.16 | 34.61 | 27.07 | 100.1 | 108.8 | 1.004 | .104 | 5.2 |
| 600 | 6.49 | 19.14 | 34.57 | 27.17 | 90.5 | 99.6 | 1.108 | 0 | 0 |

| STATION | DATE | TIME | LATITUDE | LONGITUDE | D |
|---|---|---|---|---|---|
| H 134 | DEC 19, 1963 | 0553-0648 | 14° 31.0'S | 095° 14.0'W | 18 |

OBSERVED AND COMPUTED VALUES AT OBSERVED DEPTHS

| Z | T | Cl | S | $O_2$ | $\sigma_T$ | $\delta_T$ | AOU | $PO_4$ | $NO_3$ | $SiO_4$ | $NO_2$ |
|---|---|---|---|---|---|---|---|---|---|---|---|
| (m) | (°C) | (‰) | (‰) | (ml/L) | (gm/L) | (cl/L) | (ml/L) | —— | (µg at./L) | —— | |
| 0 | 21.90 | 19.86 | 35.88 | 5.00 | 24.93 | 303.2 | -.17 | .53 | 1.1 | .8 | .03 |
| 50 | 21.73 | 19.85 | 35.86 | 4.99 | 24.97 | 300.0 | -.15 | .35 | .7 | .5 | .02 |
| 75 | 21.62 | 19.85 | 35.86 | 4.93 | 25.00 | 297.1 | -.08 | .34 | .7 | .4 | .02 |
| 100 | 20.53 | 19.76 | 35.70 | 4.78 | 25.17 | 280.5 | .17 | .34 | 1.2 | .5 | -0 |
| 150 | 18.90 | 19.62 | 35.44 | 4.62 | 25.40 | 258.2 | .48 | .50 | 4.4 | .8 | .48 |
| 199 | 15.01 | 19.33 | 34.92 | 3.56 | 25.93 | 208.5 | 1.95 | .96 | 14.7 | 3.6 | .02 |
| 297 | 10.36 | 19.22 | 34.72 | .54 | 26.69 | 135.9 | 5.54 | 2.21 | 33.0 | 27.4 | 0 |
| 389 | 8.74 | 19.19 | 34.67 | .69 | 26.92 | 114.3 | 5.62 | 2.32 | 39.1 | 32.4 | .01 |
| 575 | 6.61 | 19.14 | 34.58 | .87 | 27.16 | 91.5 | 5.77 | 2.50 | 44.8 | 38.2 | 0 |

INTERPOLATED AND COMPUTED VALUES AT STANDARD DEPTHS

| Z | T | Cl | S | $\sigma_T$ | $\delta_T$ | $\delta$ | $\Delta D_{Z/0}$ | $\Delta D_{Z/Z\,MAX}$ | $Q_Z$ |
|---|---|---|---|---|---|---|---|---|---|
| (m) | (°C) | (‰) | (‰) | (gm/L) | (cl/T) | (cl/T) | (dyn m) | (dyn m) | (m-dyn m) |
| 0 | 21.90 | 19.86 | 35.88 | 24.93 | 303.2 | 303.3 | 0 | 1.080 | 250.4 |
| 10 | 21.88 | 19.86 | 35.87 | 24.93 | 302.9 | 303.4 | .030 | 1.050 | 239.8 |
| 20 | 21.86 | 19.86 | 35.87 | 24.94 | 302.4 | 303.3 | .061 | 1.020 | 229.4 |
| 30 | 21.83 | 19.86 | 35.87 | 24.94 | 301.8 | 303.1 | .091 | .989 | 219.4 |
| 50 | 21.73 | 19.85 | 35.86 | 24.96 | 300.0 | 302.0 | .151 | .929 | 200.2 |
| 75 | 21.62 | 19.85 | 35.86 | 24.99 | 297.1 | 300.0 | .227 | .854 | 177.9 |
| 100 | 20.53 | 19.76 | 35.70 | 25.17 | 280.5 | 284.2 | .300 | .781 | 157.5 |
| 150 | 18.90 | 19.62 | 35.44 | 25.40 | 258.2 | 263.5 | .437 | .644 | 121.9 |
| 200 | 14.95 | 19.33 | 34.92 | 25.94 | 207.6 | 213.6 | .556 | .524 | 92.7 |
| 250 | 12.36 | 19.25 | 34.77 | 26.36 | 167.1 | 173.7 | .653 | .428 | 68.9 |
| 300 | 10.30 | 19.22 | 34.72 | 26.70 | 135.1 | 141.9 | .732 | .349 | 49.5 |
| 400 | 8.59 | 19.18 | 34.66 | 26.94 | 112.7 | 120.5 | .863 | .217 | 21.2 |
| 500 | 7.37 | 19.15 | 34.60 | 27.07 | 99.6 | 108.2 | .977 | .103 | 5.2 |
| 600 | 6.38 | 19.14 | 34.57 | 27.19 | 89.0 | 98.0 | 1.080 | 0 | 0 |

| STATION | DATE | TIME | LATITUDE | LONGITUDE | D |
|---|---|---|---|---|---|
| H 135 | DEC 19, 1963 | 2010-2055 | 13° 45.0'S | 094° 59.3'W | |

OBSERVED AND COMPUTED VALUES AT OBSERVED DEPTHS

| Z | T | Cl | S | $O_2$ | $\sigma_T$ | $\delta_T$ | AOU | $PO_4$ | $NO_3$ | $SiO_4$ | $NO_2$ |
|---|---|---|---|---|---|---|---|---|---|---|---|
| (m) | (°C) | (‰) | (‰) | (ml/L) | (gm/L) | (cl/L) | (ml/L) | —— | (µg at./L) | —— | |
| 0 | 21.70 | 19.72 | 35.62 | 5.00 | 24.80 | 316.2 | -.15 | .67 | 6.0 | 1.2 | .06 |
| 49 | 21.42 | 19.70 | 35.59 | 4.99 | 24.85 | 311.4 | -.11 | .54 | 6.2 | .8 | .14 |
| 73 | 20.85 | 19.69 | 35.57 | 4.92 | 24.99 | 297.9 | .00 | .63 | 5.7 | 1.2 | .15 |
| 97 | 20.82 | 19.74 | 35.66 | 4.89 | 25.06 | 290.5 | .03 | .59 | 2.1 | 1.1 | .20 |
| 146 | 16.68 | 19.47 | 35.17 | 4.05 | 25.74 | 226.2 | 1.27 | .81 | 10.9 | 1.9 | .54 |
| 225 | 12.12 | 19.28 | 34.83 | .26 | 26.45 | 158.6 | 5.59 | 2.32 | 28.1 | 25.1 | .02 |
| 312 | 10.57 | 19.22 | 34.72 | .38 | 26.66 | 139.4 | 5.68 | 2.27 | 35.1 | 30.7 | 0 |
| 405 | 9.04 | 19.20 | 34.69 | .61 | 26.89 | 117.5 | 5.66 | 2.33 | 38.3 | 35.0 | .02 |
| 571 | 7.24 | 19.18 | 34.65 | .86 | 27.13 | 94.3 | 5.68 | 2.46 | 43.8 | 34.0 | 0 |

INTERPOLATED AND COMPUTED VALUES AT STANDARD DEPTHS

| Z | T | Cl | S | $\sigma_T$ | $\delta_T$ | $\delta$ | $\Delta D_{Z/0}$ | $\Delta D_{Z/Z\,MAX}$ | $Q_Z$ |
|---|---|---|---|---|---|---|---|---|---|
| (m) | (°C) | (‰) | (‰) | (gm/L) | (cl/T) | (cl/T) | (dyn m) | (dyn m) | (m-dyn m) |
| 0 | 21.70 | 19.72 | 35.62 | 24.79 | 316.2 | 316.3 | 0 | 1.066 | 250.2 |
| 10 | 21.67 | 19.72 | 35.62 | 24.80 | 315.6 | 316.1 | .032 | 1.034 | 239.7 |
| 20 | 21.63 | 19.71 | 35.61 | 24.81 | 314.9 | 315.8 | .063 | 1.003 | 229.6 |
| 30 | 21.58 | 19.71 | 35.61 | 24.82 | 314.1 | 315.3 | .095 | .971 | 219.7 |
| 50 | 21.40 | 19.70 | 35.59 | 24.85 | 311.0 | 313.0 | .158 | .908 | 200.9 |
| 75 | 20.85 | 19.69 | 35.58 | 24.99 | 297.3 | 300.2 | .234 | .832 | 179.1 |
| 100 | 20.65 | 19.73 | 35.64 | 25.09 | 287.6 | 291.3 | .308 | .758 | 159.3 |
| 150 | 16.40 | 19.45 | 35.14 | 25.78 | 222.0 | 226.8 | .438 | .628 | 124.6 |
| 200 | 13.36 | 19.32 | 34.90 | 26.26 | 177.0 | 182.6 | .540 | .526 | 95.7 |
| 250 | 11.62 | 19.26 | 34.79 | 26.52 | 152.4 | 158.6 | .625 | .441 | 71.6 |
| 300 | 10.76 | 19.23 | 34.73 | 26.63 | 141.7 | 148.7 | .702 | .364 | 51.5 |
| 400 | 9.11 | 19.20 | 34.69 | 26.87 | 118.5 | 126.7 | .840 | .226 | 22.0 |
| 500 | 7.94 | 19.18 | 34.66 | 27.03 | 103.3 | 112.4 | .959 | .107 | 5.3 |
| 600 | 6.98 | 19.18 | 34.65 | 27.16 | 91.0 | 100.7 | 1.066 | 0 | 0 |

| STATION | DATE | TIME | LATITUDE | LONGITUDE | D |
|---|---|---|---|---|---|
| H 136 | DEC 20, 1963 | 0600-0640 | 12° 24.0'S | 095° 00.0'W | |

OBSERVED AND COMPUTED VALUES AT OBSERVED DEPTHS

| Z (m) | T (°C) | Cl (‰) | S (‰) | $O_2$ (ml/L) | $\sigma_T$ (gm/L) | $\delta_T$ (cl/L) | AOU (ml/L) | $PO_4$ (µg at./L) | $NO_3$ (µg at./L) | $SiO_4$ (µg at./L) | $NO_2$ (µg at./L) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 0 | 21.80 | 19.72 | 35.62 | 4.88 | 24.77 | 318.8 | -.04 | .64 | 7.6 | 1.8 | .13 |
| 50 | 21.62 | 19.73 | 35.64 | 5.03 | 24.83 | 312.7 | -.17 | .68 | 7.4 | 1.2 | .17 |
| 75 | 21.12 | 19.75 | 35.68 | 4.94 | 25.00 | 297.0 | -.04 | .51 | 4.2 | 1.1 | .13 |
| 100 | 18.69 | 19.58 | 35.37 | 4.29 | 25.40 | 258.4 | .83 | .66 | 8.1 | 1.4 | 1.31 |
| 149 | 14.71 | 19.33 | 34.92 | 2.30 | 25.99 | 202.3 | 3.24 | 1.43 | 21.1 | 8.2 | .03 |
| 198 | 12.04 | 19.30 | 34.87 | .24 | 26.50 | 154.4 | 5.62 | -0 | 29.2 | 24.5 | .05 |
| 312 | 10.68 | 19.29 | 34.85 | .66 | 26.73 | 131.9 | 5.38 | 2.04 | 35.9 | 30.4 | .01 |
| 386 | 9.60 | 19.30 | 34.87 | .50 | 26.93 | 112.9 | 5.68 | 2.31 | 38.1 | 36.0 | .01 |
| 570 | 7.40 | 19.17 | 34.63 | .71 | 27.09 | 97.8 | 5.81 | 2.32 | 42.3 | 43.5 | .01 |

INTERPOLATED AND COMPUTED VALUES AT STANDARD DEPTHS

H 136

| Z (m) | T (°C) | Cl (‰) | S (‰) | $\sigma_T$ (gm/L) | $\delta_T$ (cl/T) | $\delta$ (cl/T) | $\Delta D_{Z/0}$ (dyn m) | $\Delta D_{Z/Z\,MAX}$ (dyn m) | $Q_Z$ (m-dyn m) |
|---|---|---|---|---|---|---|---|---|---|
| 0 | 21.80 | 19.72 | 35.62 | 24.77 | 318.8 | 318.9 | 0 | 1.019 | 240.5 |
| 10 | 21.78 | 19.72 | 35.63 | 24.77 | 318.1 | 318.6 | .032 | .987 | 230.5 |
| 20 | 21.76 | 19.72 | 35.63 | 24.78 | 317.3 | 318.2 | .064 | .955 | 220.8 |
| 30 | 21.72 | 19.72 | 35.63 | 24.79 | 316.2 | 317.4 | .095 | .923 | 211.4 |
| 50 | 21.62 | 19.73 | 35.64 | 24.83 | 312.7 | 314.7 | .159 | .860 | 193.6 |
| 75 | 21.12 | 19.75 | 35.68 | 25.00 | 297.0 | 299.9 | .236 | .783 | 173.0 |
| 100 | 18.69 | 19.58 | 35.37 | 25.40 | 258.4 | 261.9 | .306 | .713 | 154.3 |
| 150 | 14.65 | 19.33 | 34.92 | 26.00 | 201.2 | 205.7 | .423 | .596 | 121.6 |
| 200 | 12.01 | 19.30 | 34.87 | 26.50 | 153.9 | 159.1 | .514 | .505 | 94.1 |
| 250 | 11.34 | 19.29 | 34.85 | 26.62 | 142.9 | 149.0 | .591 | .428 | 70.8 |
| 300 | 10.80 | 19.29 | 34.85 | 26.71 | 133.8 | 140.9 | .663 | .355 | 51.2 |
| 400 | 9.40 | 19.29 | 34.84 | 26.95 | 111.5 | 119.9 | .794 | .225 | 22.1 |
| 500 | 8.14 | 19.21 | 34.70 | 27.04 | 102.9 | 112.2 | .910 | .109 | 5.4 |
| 600 | 7.11 | 19.16 | 34.61 | 27.11 | 95.9 | 105.8 | 1.019 | 0 | 0 |

| STATION | DATE | TIME | LATITUDE | LONGITUDE | D |
|---|---|---|---|---|---|
| H 137 | DEC 20, 1963 | 1200-1237 | 11° 26.7'S | 095° 00.7'W | 18 |

OBSERVED AND COMPUTED VALUES AT OBSERVED DEPTHS

| Z (m) | T (°C) | Cl (‰) | S (‰) | $O_2$ (ml/L) | $\sigma_T$ (gm/L) | $\delta_T$ (cl/L) | AOU (ml/L) | $PO_4$ (µg at./L) | $NO_3$ (µg at./L) | $SiO_4$ (µg at./L) | $NO_2$ (µg at./L) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 0 | 22.40 | 19.71 | 35.61 | 4.95 | 24.58 | 336.2 | -.15 | .65 | 7.2 | 1.8 | .17 |
| 50 | 21.77 | 19.71 | 35.61 | 4.99 | 24.76 | 319.3 | -.14 | .59 | 6.7 | 1.6 | .16 |
| 75 | 19.69 | 19.64 | 35.48 | 4.90 | 25.23 | 275.0 | .13 | .66 | 4.9 | 1.8 | .40 |
| 100 | 19.20 | 19.62 | 35.44 | 4.76 | 25.33 | 265.5 | .31 | .65 | 5.4 | 1.5 | 1.01 |
| 149 | 13.12 | 19.28 | 34.83 | 2.28 | 26.26 | 177.3 | 3.45 | 2.09 | 26.8 | 20.7 | .02 |
| 199 | 11.56 | 19.27 | 34.81 | .33 | 26.55 | 149.8 | 5.59 | 2.36 | 33.5 | 28.2 | .01 |
| 298 | 10.48 | 19.24 | 34.76 | .28 | 26.70 | 135.2 | 5.79 | 2.37 | 37.0 | 34.3 | -0 |
| 393 | 9.20 | 19.20 | 34.69 | .38 | 26.86 | 120.0 | 5.87 | 2.49 | 39.7 | 38.0 | .01 |
| 580 | 7.28 | 19.16 | 34.61 | .33 | 27.10 | 97.6 | 6.21 | 2.70 | 46.8 | 47.6 | .01 |

H 137

INTERPOLATED AND COMPUTED VALUES AT STANDARD DEPTHS

| Z (m) | T (°C) | Cl (‰) | S (‰) | $\sigma_T$ (gm/L) | $\delta_T$ (cl/T) | $\delta$ (cl/T) | $\Delta D_{Z/0}$ (dyn m) | $\Delta D_{Z/Z\,MAX}$ (dyn m) | $Q_Z$ (m-dyn m) |
|---|---|---|---|---|---|---|---|---|---|
| 0 | 22.40 | 19.71 | 35.61 | 24.58 | 336.2 | 336.3 | 0 | 1.019 | 242.7 |
| 10 | 22.33 | 19.71 | 35.61 | 24.60 | 334.3 | 334.8 | .034 | .985 | 232.7 |
| 20 | 22.24 | 19.71 | 35.61 | 24.63 | 332.0 | 332.9 | .067 | .952 | 223.0 |
| 30 | 22.13 | 19.71 | 35.61 | 24.66 | 329.0 | 330.2 | .100 | .919 | 213.6 |
| 50 | 21.77 | 19.71 | 35.61 | 24.76 | 319.3 | 321.3 | .165 | .853 | 195.9 |
| 75 | 19.69 | 19.64 | 35.48 | 25.23 | 275.0 | 277.7 | .240 | .779 | 175.5 |
| 100 | 19.20 | 19.62 | 35.44 | 25.33 | 265.5 | 269.1 | .308 | .710 | 156.9 |
| 150 | 13.08 | 19.28 | 34.83 | 26.26 | 176.6 | 180.8 | .421 | .598 | 124.2 |
| 200 | 11.55 | 19.27 | 34.81 | 26.55 | 149.6 | 154.6 | .505 | .514 | 96.4 |
| 250 | 10.95 | 19.25 | 34.78 | 26.63 | 141.6 | 147.5 | .580 | .438 | 72.6 |
| 300 | 10.45 | 19.24 | 34.76 | 26.70 | 134.6 | 141.7 | .653 | .366 | 52.5 |
| 400 | 9.11 | 19.20 | 34.68 | 26.87 | 118.9 | 127.1 | .787 | .232 | 22.6 |
| 500 | 8.01 | 19.17 | 34.63 | 27.00 | 106.1 | 115.3 | .908 | .110 | 5.5 |
| 600 | 7.11 | 19.16 | 34.61 | 27.12 | 95.6 | 105.5 | 1.019 | 0 | 0 |

| STATION | DATE | TIME | LATITUDE | LONGITUDE | D |
|---|---|---|---|---|---|
| H 138 | DEC 20, 1963 | 1800-1835 | 10° 26.8'S | 095° 00.3'W | |

OBSERVED AND COMPUTED VALUES AT OBSERVED DEPTHS

| Z (m) | T (°C) | Cl (‰) | S (‰) | $O_2$ (ml/L) | $\sigma_T$ (gm/L) | $\delta_T$ (cl/L) | AOU (ml/L) | $PO_4$ (µg at./L) | $NO_3$ (µg at./L) | $SiO_4$ (µg at./L) | $NO_2$ (µg at./L) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 0 | 22.80 | 19.32 | 34.90 | 4.93 | 23.94 | 397.9 | -.14 | .70 | 7.7 | 2.3 | .10 |
| 50 | 22.30 | 19.62 | 35.44 | 4.97 | 24.49 | 345.2 | -.16 | .55 | 7.6 | 2.1 | .15 |
| 75 | 20.37 | 19.66 | 35.52 | 4.69 | 25.08 | 289.5 | .28 | .56 | 5.0 | 1.4 | .39 |
| 100 | 18.10 | 19.53 | 35.28 | 3.80 | 25.48 | 250.9 | 1.38 | .98 | 12.1 | 2.2 | 1.01 |
| 150 | 13.24 | 19.28 | 34.83 | .54 | 26.23 | 179.6 | 5.17 | -0 | -0 | -0 | -0 |
| 200 | 11.82 | 19.27 | 34.81 | .42 | 26.50 | 154.4 | 5.47 | 2.11 | 32.4 | 2.7 | .02 |
| 296 | 10.81 | 19.24 | 34.76 | .32 | 26.64 | 140.8 | 5.70 | 2.29 | 37.8 | 34.0 | 0 |
| 388 | 9.75 | 19.22 | 34.72 | .30 | 26.80 | 125.9 | 5.87 | 2.67 | 38.4 | 37.5 | 0 |
| 575 | 7.42 | 19.14 | 34.58 | .39 | 27.05 | 102.1 | 6.13 | 2.87 | 45.7 | 46.2 | 0 |

INTERPOLATED AND COMPUTED VALUES AT STANDARD DEPTHS

| Z (m) | T (°C) | Cl (‰) | S (‰) | $\sigma_T$ (gm/L) | $\delta_T$ (cl/T) | $\delta$ (cl/T) | $\Delta D_{Z/0}$ (dyn m) | $\Delta D_{Z/Z\,MAX}$ (dyn m) | $Q_Z$ (m-dynm) |
|---|---|---|---|---|---|---|---|---|---|
| 0 | 22.80 | 19.32 | 34.90 | 23.94 | 397.9 | 398.0 | 0 | 1.067 | 251.4 |
| 10 | 22.74 | 19.35 | 34.96 | 24.00 | 392.0 | 392.5 | .040 | 1.027 | 240.9 |
| 20 | 22.67 | 19.39 | 35.04 | 24.07 | 384.7 | 385.6 | .078 | .988 | 230.9 |
| 30 | 22.59 | 19.45 | 35.13 | 24.17 | 375.3 | 376.6 | .117 | .950 | 221.2 |
| 50 | 22.30 | 19.62 | 35.44 | 24.49 | 345.2 | 347.2 | .189 | .878 | 202.9 |
| 75 | 20.37 | 19.66 | 35.52 | 25.07 | 289.5 | 292.3 | .269 | .798 | 182.0 |
| 100 | 18.10 | 19.53 | 35.28 | 25.48 | 250.9 | 254.4 | .337 | .729 | 162.9 |
| 150 | 13.24 | 19.28 | 34.83 | 26.23 | 179.6 | 183.8 | .447 | .620 | 129.1 |
| 200 | 11.82 | 19.27 | 34.81 | 26.50 | 154.4 | 159.6 | .533 | .534 | 100.3 |
| 250 | 11.25 | 19.25 | 34.78 | 26.58 | 146.7 | 152.8 | .611 | .456 | 75.5 |
| 300 | 10.76 | 19.24 | 34.76 | 26.65 | 140.0 | 147.1 | .686 | .381 | 54.6 |
| 400 | 9.57 | 19.21 | 34.71 | 26.82 | 124.1 | 132.6 | .825 | .241 | 23.5 |
| 500 | 8.25 | 19.16 | 34.62 | 26.96 | 110.6 | 120.0 | .952 | .115 | 5.7 |
| 600 | 7.17 | 19.13 | 34.57 | 27.07 | 99.6 | 109.5 | 1.067 | 0 | 0 |

| STATION | DATE | TIME | LATITUDE | LONGITUDE | D |
|---|---|---|---|---|---|
| h 139 | DEC 21, 1963 | 0610-0653 | 09° 27.7'S | 094° 58.3'W | 17 |

OBSERVED AND COMPUTED VALUES AT OBSERVED DEPTHS

| Z (m) | T (°C) | Cl (‰) | S (‰) | $O_2$ (ml/L) | $\sigma_T$ (gm/L) | $\delta_T$ (cl/L) | AOU (ml/L) | $PO_4$ (µg at./L) | $NO_3$ (µg at./L) | $SiO_4$ (µg at./L) | $NO_2$ (µg at./L) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 0 | 23.00 | 19.58 | 35.37 | 4.85 | 24.24 | 369.5 | -.09 | .63 | 6.9 | 1.9 | .16 |
| 50 | 22.45 | 19.59 | 35.39 | 4.93 | 24.41 | 353.2 | -.13 | .57 | 7.7 | 1.9 | .17 |
| 75 | 18.01 | 19.50 | 35.23 | 2.92 | 25.46 | 252.7 | 2.27 | 1.26 | 18.3 | 4.9 | 1.21 |
| 100 | 14.57 | 19.36 | 34.97 | .48 | 26.06 | 195.5 | 5.08 | 1.98 | 30.3 | 14.3 | .42 |
| 150 | 12.74 | 19.31 | 34.88 | .32 | 26.37 | 166.1 | 5.45 | 2.24 | 33.9 | 25.1 | .02 |
| 200 | 12.15 | 19.31 | 34.88 | .48 | 26.49 | 155.1 | 5.36 | 2.17 | 34.9 | 26.5 | .01 |
| 297 | 11.13 | 19.28 | 34.83 | .34 | 26.64 | 140.9 | 5.64 | 2.28 | 36.6 | 30.9 | .01 |
| 390 | 10.02 | 19.26 | 34.79 | .45 | 26.81 | 124.9 | 5.68 | 2.41 | 37.2 | 34.7 | .01 |
| 576 | 7.29 | 19.15 | 34.60 | .54 | 27.08 | 99.0 | 6.00 | 2.76 | 43.9 | 41.5 | 0 |

INTERPOLATED AND COMPUTED VALUES AT STANDARD DEPTHS

| Z (m) | T (°C) | Cl (‰) | S (‰) | $\sigma_T$ (gm/L) | $\delta_T$ (cl/T) | $\delta$ (cl/T) | $\Delta D_{Z/0}$ (dyn m) | $\Delta D_{Z/Z\,MAX}$ (dyn m) | $Q_Z$ (m-dynm) |
|---|---|---|---|---|---|---|---|---|---|
| 0 | 23.00 | 19.58 | 35.37 | 24.23 | 369.5 | 369.6 | 0 | 1.020 | 245.3 |
| 10 | 22.94 | 19.58 | 35.37 | 24.25 | 367.7 | 368.2 | .037 | .983 | 235.3 |
| 20 | 22.86 | 19.58 | 35.38 | 24.28 | 365.4 | 366.3 | .074 | .947 | 225.6 |
| 30 | 22.76 | 19.58 | 35.38 | 24.31 | 362.5 | 363.8 | .110 | .910 | 216.3 |
| 50 | 22.45 | 19.59 | 35.39 | 24.41 | 353.2 | 355.2 | .182 | .838 | 198.9 |
| 75 | 18.01 | 19.50 | 35.23 | 25.46 | 252.7 | 255.3 | .258 | .762 | 178.9 |
| 100 | 14.57 | 19.36 | 34.97 | 26.06 | 195.5 | 198.5 | .315 | .705 | 160.5 |
| 150 | 12.74 | 19.31 | 34.88 | 26.37 | 166.1 | 170.2 | .407 | .613 | 127.6 |
| 200 | 12.15 | 19.31 | 34.88 | 26.49 | 155.1 | 160.3 | .490 | .530 | 99.0 |
| 250 | 11.57 | 19.29 | 34.85 | 26.57 | 147.1 | 153.4 | .568 | .452 | 74.4 |
| 300 | 11.09 | 19.28 | 34.83 | 26.64 | 140.3 | 147.6 | .643 | .377 | 53.7 |
| 400 | 9.84 | 19.25 | 34.78 | 26.82 | 123.3 | 132.0 | .783 | .237 | 23.0 |
| 500 | 8.28 | 19.18 | 34.66 | 26.98 | 108.4 | 117.9 | .908 | .112 | 5.6 |
| 600 | 7.00 | 19.14 | 34.58 | 27.11 | 96.3 | 106.1 | 1.020 | 0 | 0 |

| STATION | DATE | TIME | LATITUDE | LONGITUDE | D |
|---|---|---|---|---|---|
| H 140 | DEC 21, 1963 | 2210-2246 | 09° 00.0'S | 094° 08.6'W | |

OBSERVED AND COMPUTED VALUES AT OBSERVED DEPTHS

| Z (m) | T (°C) | Cl (‰) | S (‰) | $O_2$ (ml/L) | $\sigma_T$ (gm/L) | $\delta_T$ (cl/L) | AOU (ml/L) | $PO_4$ (µg at./L) | $NO_3$ (µg at./L) | $SiO_4$ (µg at./L) | $NO_2$ (µg at./L) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 0 | 23.60 | 19.42 | 35.08 | 4.76 | 23.84 | 407.0 | -.04 | .66 | 7.5 | 3.3 | .14 |
| 49 | 22.77 | 19.63 | 35.46 | 4.83 | 24.37 | 356.7 | -.06 | .62 | 7.2 | 1.7 | .16 |
| 74 | 20.47 | 19.57 | 35.35 | 3.87 | 24.93 | 303.8 | 1.09 | .98 | 13.5 | 3.4 | .78 |
| 99 | 15.17 | 19.45 | 35.14 | 1.11 | 26.06 | 196.1 | 4.37 | 2.04 | 26.6 | 11.2 | .44 |
| 148 | 13.07 | 19.36 | 34.97 | .19 | 26.38 | 165.7 | 5.54 | 2.06 | 32.7 | 24.2 | .02 |
| 223 | 12.07 | 19.34 | 34.94 | .68 | 26.55 | 149.7 | 5.17 | 2.05 | 33.0 | 25.6 | .02 |
| 319 | 11.05 | 19.30 | 34.87 | .19 | 26.68 | 136.9 | 5.80 | 2.29 | 36.6 | 32.3 | .01 |
| 416 | 9.57 | 19.22 | 34.72 | .24 | 26.83 | 123.1 | 5.95 | 2.41 | 38.3 | 36.8 | .01 |
| 595 | 6.99 | 19.17 | 34.63 | .69 | 27.15 | 92.4 | 5.89 | -0 | 45.9 | 34.1 | -0 |

INTERPOLATED AND COMPUTED VALUES AT STANDARD DEPTHS

| Z (m) | T (°C) | Cl (‰) | S (‰) | $\sigma_T$ (gm/L) | $\delta_T$ (cl/T) | $\delta$ (cl/T) | $\Delta D_{Z/0}$ (dyn m) | $\Delta D_{Z/Z MAX}$ (dyn m) | $Q_Z$ (m-dynm) |
|---|---|---|---|---|---|---|---|---|---|
| 0 | 23.60 | 19.42 | 35.08 | 23.84 | 407.0 | 407.1 | 0 | 1.040 | 244.6 |
| 10 | 23.51 | 19.44 | 35.13 | 23.90 | 401.2 | 401.7 | .040 | .999 | 234.4 |
| 20 | 23.39 | 19.47 | 35.18 | 23.78 | 394.1 | 395.0 | .080 | .959 | 224.6 |
| 30 | 23.23 | 19.51 | 35.25 | 24.07 | 384.8 | 386.0 | .119 | .920 | 215.2 |
| 50 | 22.71 | 19.63 | 35.46 | 24.39 | 355.1 | 357.1 | .194 | .846 | 197.6 |
| 75 | 20.30 | 19.57 | 35.34 | 24.96 | 300.2 | 303.0 | .276 | .763 | 177.4 |
| 100 | 15.12 | 19.45 | 35.13 | 26.06 | 195.3 | 198.4 | .339 | .701 | 159.1 |
| 150 | 13.04 | 19.36 | 34.97 | 26.38 | 165.2 | 169.3 | .431 | .609 | 126.4 |
| 200 | 12.34 | 19.34 | 34.95 | 26.50 | 153.9 | 159.2 | .513 | .527 | 96.0 |
| 250 | 11.74 | 19.33 | 34.91 | 26.59 | 145.6 | 151.9 | .591 | .449 | 73.6 |
| 300 | 11.23 | 19.31 | 34.88 | 26.66 | 139.1 | 146.4 | .665 | .374 | 53.0 |
| 400 | 9.79 | 19.23 | 34.74 | 26.80 | 125.1 | 133.8 | .805 | .234 | 22.6 |
| 500 | 8.24 | 19.19 | 34.66 | 26.99 | 107.3 | 116.7 | .931 | .109 | 5.5 |
| 600 | 6.93 | 19.17 | 34.63 | 27.16 | 91.6 | 101.3 | 1.040 | 0 | 0 |

H 140

| STATION | DATE | TIME | LATITUDE | LONGITUDE | D |
|---|---|---|---|---|---|
| H 141 | DEC 22, 1963 | 0600-0637 | 08° 01.0'S | 093° 12.2'W | 22 |

OBSERVED AND COMPUTED VALUES AT OBSERVED DEPTHS

| Z (m) | T (°C) | Cl (‰) | S (‰) | $O_2$ (ml/L) | $\sigma_T$ (gm/L) | $\delta_T$ (cl/L) | AOU (ml/L) | $PO_4$ (µg at./L) | $NO_3$ (µg at./L) | $SiO_4$ (µg at./L) | $NO_2$ (µg at./L) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 0 | 23.40 | 19.41 | 35.07 | 4.79 | 23.89 | 402.7 | -.06 | .54 | 7.3 | 3.1 | .13 |
| 49 | 22.69 | 19.64 | 35.48 | 4.52 | 24.41 | 353.2 | .26 | .60 | 7.8 | 1.7 | .17 |
| 73 | 21.35 | 19.62 | 35.44 | 4.83 | 24.76 | 320.0 | .06 | .72 | 7.3 | 1.6 | -0 |
| 97 | 16.77 | 19.46 | 35.16 | 1.88 | 25.71 | 229.5 | 3.44 | 1.75 | -0 | 8.4 | -0 |
| 146 | 13.18 | 19.35 | 34.96 | .23 | 26.34 | 169.2 | 5.49 | 1.98 | 31.9 | 20.9 | .02 |
| 218 | 11.62 | 19.33 | 34.92 | .77 | 26.62 | 142.9 | 5.14 | 1.94 | 34.3 | 26.7 | .01 |
| 303 | 10.82 | 19.28 | 34.83 | .24 | 26.70 | 135.6 | 5.78 | 2.24 | 37.5 | 35.3 | 0 |
| 417 | 9.58 | 19.26 | 34.79 | .23 | 26.88 | 117.9 | 5.96 | 2.39 | 40.3 | 38.2 | .01 |
| 604 | 7.03 | 19.23 | 34.74 | .44 | 27.23 | 84.8 | 6.13 | 2.86 | 46.4 | 49.0 | 0 |

INTERPOLATED AND COMPUTED VALUES AT STANDARD DEPTHS

| Z (m) | T (°C) | Cl (‰) | S (‰) | $\sigma_T$ (gm/L) | $\delta_T$ (cl/T) | $\delta$ (cl/T) | $\Delta D_{Z/0}$ (dyn m) | $\Delta D_{Z/Z MAX}$ (dyn m) | $Q_Z$ (m-dynm) |
|---|---|---|---|---|---|---|---|---|---|
| 0 | 23.40 | 19.41 | 35.06 | 23.89 | 402.7 | 402.8 | 0 | 1.031 | 237.7 |
| 10 | 23.32 | 19.44 | 35.11 | 23.95 | 397.1 | 397.6 | .040 | .991 | 227.6 |
| 20 | 23.22 | 19.47 | 35.17 | 24.02 | 390.0 | 390.9 | .079 | .952 | 217.9 |
| 30 | 23.09 | 19.51 | 35.25 | 24.12 | 380.9 | 382.1 | .118 | .913 | 208.5 |
| 50 | 22.65 | 19.64 | 35.48 | 24.42 | 352.1 | 354.1 | .192 | .839 | 191.0 |
| 75 | 21.06 | 19.61 | 35.43 | 24.82 | 313.6 | 316.4 | .276 | .756 | 171.1 |
| 100 | 16.50 | 19.45 | 35.13 | 25.75 | 225.0 | 228.3 | .344 | .688 | 153.0 |
| 150 | 13.07 | 19.35 | 34.95 | 26.36 | 167.4 | 171.5 | .444 | .588 | 121.1 |
| 200 | 11.96 | 19.33 | 34.93 | 26.56 | 148.5 | 153.7 | .525 | .506 | 93.8 |
| 250 | 11.29 | 19.31 | 34.88 | 26.65 | 139.9 | 146.0 | .600 | .431 | 70.4 |
| 300 | 10.84 | 19.28 | 34.83 | 26.69 | 135.8 | 142.9 | .672 | .359 | 50.6 |
| 400 | 9.74 | 19.26 | 34.80 | 26.86 | 120.2 | 128.8 | .808 | .223 | 21.5 |
| 500 | 8.33 | 19.24 | 34.76 | 27.05 | 101.7 | 111.2 | .928 | .103 | 5.2 |
| 600 | 7.08 | 19.23 | 34.74 | 27.22 | 85.4 | 95.3 | 1.031 | 0 | 0 |

H 141

| STATION | DATE | TIME | LATITUDE | LONGITUDE | D |
|---|---|---|---|---|---|
| H 142 | DEC 22, 1963 | 1400-1435 | 07° 05.0'S | 092° 13.0'W | 25 |

OBSERVED AND COMPUTED VALUES AT OBSERVED DEPTHS

| Z | T | Cl | S | $O_2$ | $\sigma_T$ | $\delta_T$ | AOU | $PO_4$ | $NO_3$ | $SiO_4$ | $NO_2$ |
|---|---|---|---|---|---|---|---|---|---|---|---|
| (m) | (°C) | (‰) | (‰) | (ml/L) | (gm/L) | (cl/L) | (ml/L) | (μg at./L) | | | |
| 0 | 23.90 | 19.50 | 35.23 | 5.07 | 23.86 | 405.0 | -.38 | .61 | 7.3 | 2.5 | .13 |
| 50 | 22.60 | 19.81 | 35.79 | 4.94 | 24.66 | 328.6 | -.17 | .65 | 8.8 | 2.4 | .20 |
| 74 | 21.62 | 19.60 | 35.41 | 4.29 | 24.65 | 329.7 | .58 | .82 | 10.5 | 2.9 | .66 |
| 99 | 16.47 | 19.67 | 35.53 | 1.64 | 26.07 | 195.2 | 3.69 | 1.65 | 24.0 | 8.4 | .43 |
| 149 | 13.25 | 19.38 | 35.01 | .30 | 26.37 | 166.5 | 5.41 | 2.15 | 32.5 | 21.5 | .02 |
| 222 | 12.07 | 19.38 | 35.01 | .71 | 26.60 | 144.4 | 5.14 | 2.12 | 33.8 | 25.3 | .01 |
| 310 | 11.21 | 19.36 | 34.97 | .56 | 26.74 | 131.7 | 5.40 | 2.23 | 36.2 | 30.0 | .01 |
| 415 | 10.03 | 19.30 | 34.87 | .18 | 26.86 | 119.8 | 5.94 | 2.37 | 38.8 | 38.0 | .01 |
| 488 | 8.65 | 19.24 | 34.76 | .16 | 27.00 | 106.3 | 6.16 | 2.41 | 41.5 | 39.0 | .01 |

INTERPOLATED AND COMPUTED VALUES AT STANDARD DEPTHS

| Z | T | Cl | S | $\sigma_T$ | $\delta_T$ | $\delta$ | $\Delta D_{Z/0}$ | $\Delta D_{Z/Z\,MAX}$ | $Q_Z$ |
|---|---|---|---|---|---|---|---|---|---|
| (m) | (°C) | (‰) | (‰) | (gm/L) | (cl/T) | (cl/T) | (dyn m) | (dyn m) | (m-dyn m) |
| 0 | 23.90 | 19.50 | 35.23 | 23.86 | 405.0 | 405.1 | 0 | .914 | 180.1 |
| 10 | 23.76 | 19.53 | 35.29 | 23.95 | 396.5 | 397.0 | .040 | .874 | 171.2 |
| 20 | 23.58 | 19.58 | 35.37 | 24.06 | 385.9 | 386.8 | .079 | .834 | 162.6 |
| 30 | 23.34 | 19.63 | 35.46 | 24.21 | 372.2 | 373.5 | .117 | .796 | 154.5 |
| 50 | 22.60 | 19.81 | 35.79 | 24.66 | 328.6 | 330.6 | .188 | .726 | 139.3 |
| 75 | 21.47 | 19.60 | 35.41 | 24.70 | 325.5 | 328.4 | .270 | .644 | 122.2 |
| 100 | 16.39 | 19.66 | 35.52 | 26.07 | 194.5 | 197.8 | .336 | .578 | 106.9 |
| 150 | 13.23 | 19.38 | 35.01 | 26.37 | 166.2 | 170.4 | .428 | .486 | 80.3 |
| 200 | 12.38 | 19.38 | 35.01 | 26.54 | 150.2 | 155.5 | .509 | .404 | 58.0 |
| 250 | 11.76 | 19.37 | 35.00 | 26.65 | 139.9 | 146.2 | .585 | .329 | 39.7 |
| 300 | 11.29 | 19.36 | 34.98 | 26.72 | 132.9 | 140.2 | .656 | .257 | 25.1 |
| 400 | 10.18 | 19.31 | 34.88 | 26.84 | 121.3 | 130.2 | .792 | .122 | 6.1 |
| 500 | 8.44 | 19.23 | 34.74 | 27.02 | 104.2 | 113.8 | .914 | 0 | 0 |

| STATION | DATE | TIME | LATITUDE | LONGITUDE | D |
|---|---|---|---|---|---|
| H 143 | DEC 22, 1963 | 2210-2245 | 06° 13.0'S | 091° 15.0'W | |

OBSERVED AND COMPUTED VALUES AT OBSERVED DEPTHS

| Z | T | Cl | S | $O_2$ | $\sigma_T$ | $\delta_T$ | AOU | $PO_4$ | $NO_3$ | $SiO_4$ | $NO_2$ |
|---|---|---|---|---|---|---|---|---|---|---|---|
| (m) | (°C) | (‰) | (‰) | (ml/L) | (gm/L) | (cl/L) | (ml/L) | (μg at./L) | | | |
| 0 | 23.40 | 19.61 | 35.43 | 4.82 | 24.16 | 376.6 | -.10 | .63 | 6.8 | 1.6 | .15 |
| 50 | 22.42 | 19.61 | 35.43 | 4.69 | 24.44 | 349.8 | .11 | .70 | 9.1 | 2.1 | .28 |
| 75 | 17.03 | 19.47 | 35.17 | 1.86 | 25.66 | 234.1 | 3.43 | 1.50 | 26.7 | 11.4 | 1.41 |
| 100 | 14.88 | 19.50 | 35.23 | 1.07 | 26.19 | 183.4 | 4.44 | 1.80 | 28.9 | 16.9 | .18 |
| 150 | 13.19 | 19.45 | 35.14 | 1.08 | 26.48 | 156.1 | 4.63 | 2.02 | 33.4 | 22.2 | .02 |
| 220 | 12.76 | 19.36 | 34.97 | .31 | 26.44 | 159.8 | 5.46 | 2.35 | 34.6 | 26.2 | .04 |
| 322 | 11.90 | 19.37 | 34.99 | .33 | 26.62 | 142.6 | 5.54 | 2.18 | 35.5 | 28.3 | .01 |
| 416 | 10.25 | 19.29 | 34.85 | .22 | 26.81 | 124.7 | 5.87 | 2.29 | 38.3 | 35.3 | .02 |
| 598 | 7.15 | 19.19 | 34.67 | .21 | 27.16 | 91.8 | 6.34 | 2.40 | 46.2 | 32.2 | -0 |

INTERPOLATED AND COMPUTED VALUES AT STANDARD DEPTHS

| Z | T | Cl | S | $\sigma_T$ | $\delta_T$ | $\delta$ | $\Delta D_{Z/0}$ | $\Delta D_{Z/Z\,MAX}$ | $Q_Z$ |
|---|---|---|---|---|---|---|---|---|---|
| (m) | (°C) | (‰) | (‰) | (gm/L) | (cl/T) | (cl/T) | (dyn m) | (dyn m) | (m-dynm) |
| 0 | 23.40 | 19.61 | 35.43 | 24.16 | 376.6 | 376.8 | 0 | 1.019 | 247.0 |
| 10 | 23.29 | 19.61 | 35.43 | 24.19 | 373.7 | 374.2 | .038 | .982 | 237.0 |
| 20 | 23.15 | 19.61 | 35.42 | 24.23 | 369.9 | 370.8 | .075 | .945 | 227.3 |
| 30 | 22.98 | 19.61 | 35.42 | 24.28 | 365.1 | 366.4 | .112 | .908 | 218.1 |
| 50 | 22.42 | 19.61 | 35.43 | 24.44 | 349.8 | 351.8 | .183 | .836 | 200.7 |
| 75 | 17.03 | 19.47 | 35.17 | 25.66 | 234.1 | 236.6 | .257 | .762 | 180.7 |
| 100 | 14.88 | 19.50 | 35.23 | 26.19 | 183.4 | 186.5 | .310 | .710 | 162.3 |
| 150 | 13.19 | 19.45 | 35.14 | 26.48 | 156.1 | 160.3 | .397 | .623 | 129.0 |
| 200 | 12.87 | 19.38 | 35.01 | 26.45 | 158.9 | 164.3 | .478 | .542 | 99.9 |
| 250 | 12.47 | 19.36 | 34.98 | 26.50 | 154.1 | 160.6 | .559 | .460 | 74.8 |
| 300 | 12.06 | 19.37 | 34.99 | 26.59 | 145.8 | 153.5 | .638 | .382 | 53.7 |
| 400 | 10.50 | 19.30 | 34.87 | 26.78 | 127.5 | 136.6 | .783 | .237 | 22.8 |
| 500 | 8.68 | 19.23 | 34.74 | 26.98 | 108.0 | 117.8 | .910 | .110 | 5.5 |
| 600 | 7.12 | 19.19 | 34.67 | 27.16 | 91.5 | 101.4 | 1.019 | 0 | 0 |

| STATION | DATE | TIME | LATITUDE | LONGITUDE | D |
|---|---|---|---|---|---|
| H 144 | DEC 23, 1963 | 0610-0655 | 05° 11.5'S | 090° 36.3'W | 23 |

OBSERVED AND COMPUTED VALUES AT OBSERVED DEPTHS

| Z (m) | T (°C) | Cl (‰) | S (‰) | $O_2$ (ml/L) | $\sigma_T$ (gm/L) | $\delta_T$ (cl/L) | AOU (ml/L) | $PO_4$ (µg at./L) | $NO_3$ (µg at./L) | $SiO_4$ (µg at./L) | $NO_2$ (µg at./L) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 0 | 23.40 | 19.49 | 35.21 | 4.85 | 24.00 | 392.3 | -.12 | .47 | 5.4 | 1.9 | .10 |
| 50 | 21.19 | 19.45 | 35.14 | 4.50 | 24.57 | 338.0 | .41 | .59 | 8.9 | 3.2 | .21 |
| 75 | 17.63 | 19.49 | 35.21 | 1.66 | 25.54 | 245.2 | 3.57 | 1.95 | 22.3 | 10.5 | -0 |
| 100 | 14.14 | 19.41 | 35.07 | 1.37 | 26.23 | 180.1 | 4.23 | 1.97 | 27.9 | 18.2 | 2.18 |
| 150 | 13.35 | 19.36 | 34.97 | .95 | 26.32 | 171.1 | 4.75 | 1.69 | 31.0 | 21.4 | .30 |
| 198 | 13.08 | 19.36 | 34.97 | .86 | 26.38 | 165.9 | 4.87 | 1.79 | 31.9 | 23.8 | .02 |
| 297 | 12.36 | 19.39 | 35.03 | .25 | 26.56 | 148.4 | 5.56 | 1.85 | 34.0 | 26.5 | .01 |
| 394 | 11.03 | 19.31 | 34.88 | .32 | 26.70 | 135.2 | 5.67 | 2.31 | 35.4 | 33.2 | .01 |
| 579 | 7.30 | 19.20 | 34.69 | .26 | 27.15 | 92.5 | 6.27 | 2.80 | 44.3 | 47.8 | .01 |

INTERPOLATED AND COMPUTED VALUES AT STANDARD DEPTHS

H 144

| Z (m) | T (°C) | Cl (‰) | S (‰) | $\sigma_T$ (gm/L) | $\delta_T$ (cl/T) | $\delta$ (cl/T) | $\Delta D_{Z/0}$ (dyn m) | $\Delta D_{Z/Z\,MAX}$ (dyn m) | $Q_Z$ (m-dynm) |
|---|---|---|---|---|---|---|---|---|---|
| 0 | 23.40 | 19.49 | 35.21 | 24.00 | 392.3 | 392.4 | 0 | 1.041 | 251.6 |
| 10 | 23.15 | 19.48 | 35.20 | 24.06 | 386.2 | 386.7 | .039 | 1.002 | 241.4 |
| 20 | 22.85 | 19.48 | 35.19 | 24.14 | 378.7 | 379.6 | .077 | .963 | 231.5 |
| 30 | 22.45 | 19.47 | 35.17 | 24.24 | 369.0 | 370.3 | .115 | .926 | 222.1 |
| 50 | 21.19 | 19.45 | 35.14 | 24.56 | 338.0 | 340.0 | .186 | .855 | 204.3 |
| 75 | 17.63 | 19.49 | 35.21 | 25.54 | 245.2 | 247.8 | .259 | .781 | 183.8 |
| 100 | 14.14 | 19.41 | 35.06 | 26.22 | 180.1 | 183.1 | .313 | .728 | 165.0 |
| 150 | 13.35 | 19.36 | 34.97 | 26.32 | 171.1 | 175.3 | .403 | .638 | 130.8 |
| 200 | 13.06 | 19.36 | 34.98 | 26.38 | 165.5 | 171.0 | .489 | .551 | 101.1 |
| 250 | 12.67 | 19.38 | 35.00 | 26.48 | 155.8 | 162.5 | .573 | .468 | 75.6 |
| 300 | 12.31 | 19.39 | 35.02 | 26.56 | 147.9 | 155.7 | .652 | .389 | 54.2 |
| 400 | 10.88 | 19.30 | 34.87 | 26.72 | 133.5 | 143.0 | .802 | .239 | 22.8 |
| 500 | 8.72 | 19.23 | 34.74 | 26.98 | 108.8 | 118.6 | .932 | .108 | 5.4 |
| 600 | 6.95 | 19.19 | 34.68 | 27.19 | 88.5 | 98.2 | 1.041 | 0 | 0 |

| STATION | DATE | TIME | LATITUDE | LONGITUDE | D |
|---|---|---|---|---|---|
| H 145 | DEC 23, 1963 | 2210-2249 | 04° 31.1'S | 089° 51.7'W | |

OBSERVED AND COMPUTED VALUES AT OBSERVED DEPTHS

| Z (m) | T (°C) | Cl (‰) | S (‰) | $O_2$ (ml/L) | $\sigma_T$ (gm/L) | $\delta_T$ (cl/L) | AOU (ml/L) | $PO_4$ (µg at./L) | $NO_3$ (µg at./L) | $SiO_4$ (µg at./L) | $NO_2$ (µg at./L) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 0 | 23.50 | 19.50 | 35.23 | 4.89 | 23.98 | 393.8 | -.17 | .57 | 6.8 | 2.6 | .15 |
| 47 | 21.30 | 19.57 | 35.35 | 4.72 | 24.70 | 325.2 | .17 | .77 | 11.0 | 3.7 | .45 |
| 70 | 16.68 | 19.52 | 35.26 | 1.77 | 25.81 | 219.6 | 3.55 | 1.72 | 25.4 | 13.2 | 1.12 |
| 94 | 14.50 | 19.41 | 35.07 | .94 | 26.15 | 187.4 | 4.62 | 2.31 | 26.1 | 17.6 | .05 |
| 141 | 13.55 | 19.41 | 35.07 | 1.34 | 26.35 | 168.4 | 4.33 | 1.53 | 28.0 | 20.3 | .03 |
| 237 | 12.92 | 19.40 | 35.05 | .62 | 26.46 | 157.6 | 5.12 | 1.87 | 32.4 | 25.0 | .02 |
| 337 | 12.10 | 19.35 | 34.96 | .30 | 26.55 | 148.9 | 5.55 | 2.04 | 34.6 | 28.7 | .01 |
| 428 | 10.24 | 19.27 | 34.81 | .16 | 26.78 | 127.2 | 5.94 | 2.38 | 36.0 | 37.2 | .01 |
| 603 | 7.09 | 19.19 | 34.67 | .38 | 27.17 | 91.0 | 6.18 | 2.65 | 45.3 | 54.8 | .01 |

H 145

INTERPOLATED AND COMPUTED VALUES AT STANDARD DEPTHS

| Z (m) | T (°C) | Cl (‰) | S (‰) | $\sigma_T$ (gm/L) | $\delta_T$ (cl/T) | $\delta$ (cl/T) | $\Delta D_{Z/0}$ (dyn m) | $\Delta D_{Z/Z\,MAX}$ (dyn m) | $Q_Z$ (m-dynm) |
|---|---|---|---|---|---|---|---|---|---|
| 0 | 23.50 | 19.50 | 35.23 | 23.98 | 393.8 | 393.9 | 0 | 1.030 | 252.9 |
| 10 | 23.24 | 19.51 | 35.24 | 24.07 | 385.6 | 386.1 | .039 | .991 | 242.8 |
| 20 | 22.91 | 19.52 | 35.26 | 24.17 | 375.2 | 376.1 | .077 | .953 | 233.1 |
| 30 | 22.47 | 19.53 | 35.28 | 24.32 | 361.6 | 362.9 | .114 | .916 | 223.8 |
| 50 | 20.82 | 19.56 | 35.34 | 24.82 | 313.8 | 315.7 | .182 | .848 | 206.1 |
| 75 | 16.17 | 19.49 | 35.21 | 25.89 | 212.1 | 214.6 | .248 | .781 | 185.8 |
| 100 | 14.36 | 19.41 | 35.06 | 26.18 | 184.5 | 187.5 | .298 | .731 | 166.9 |
| 150 | 13.48 | 19.41 | 35.06 | 26.36 | 167.1 | 171.4 | .388 | .641 | 132.5 |
| 200 | 13.13 | 19.40 | 35.05 | 26.42 | 161.1 | 166.6 | .473 | .557 | 102.6 |
| 250 | 12.80 | 19.39 | 35.03 | 26.48 | 156.2 | 163.0 | .555 | .475 | 76.8 |
| 300 | 12.37 | 19.37 | 34.99 | 26.52 | 151.8 | 159.6 | .636 | .394 | 55.1 |
| 400 | 10.77 | 19.29 | 34.85 | 26.72 | 133.4 | 142.7 | .787 | .243 | 23.2 |
| 500 | 8.81 | 19.22 | 34.73 | 26.96 | 110.8 | 120.7 | .919 | .111 | 5.6 |
| 600 | 7.14 | 19.19 | 34.67 | 27.16 | 91.5 | 101.5 | 1.030 | 0 | 0 |

| STATION | DATE | TIME | LATITUDE | LONGITUDE | D |
|---|---|---|---|---|---|
| H 146 | DEC 24, 1963 | 0600-0635 | 03° 29.9'S | 088° 57.0'W | 20 |

OBSERVED AND COMPUTED VALUES AT OBSERVED DEPTHS

| Z | T | Cl | S | $O_2$ | $\sigma_T$ | $\delta_T$ | AOU | $PO_4$ | $NO_3$ | $SiO_4$ | $NO_2$ |
|---|---|---|---|---|---|---|---|---|---|---|---|
| (m) | (°C) | (‰) | (‰) | (ml/L) | (gm/L) | (cl/L) | (ml/L) | ——— ($\mu$g at./L) ——— | | | |
| 0 | 23.40 | 19.29 | 34.85 | 4.81 | 23.72 | 418.3 | -.07 | .71 | 7.2 | 5.0 | .11 |
| 50 | 21.68 | 19.48 | 35.19 | 4.70 | 24.47 | 346.9 | .17 | .74 | 9.7 | 3.4 | .25 |
| 75 | 18.71 | 19.49 | 35.21 | 2.68 | 25.27 | 270.7 | 2.45 | 1.18 | 18.5 | 8.6 | 1.53 |
| 100 | 15.26 | 19.47 | 35.17 | 1.10 | 26.07 | 195.3 | 4.37 | 2.08 | 29.9 | 15.3 | 1.99 |
| 150 | 13.63 | 19.41 | 35.07 | .92 | 26.33 | 170.0 | 4.74 | 1.70 | 30.7 | 20.1 | .03 |
| 198 | 13.26 | 19.38 | 35.01 | 1.25 | 26.37 | 166.7 | 4.46 | 1.53 | 29.8 | 22.0 | .02 |
| 298 | 12.37 | 19.39 | 35.03 | .30 | 26.56 | 148.6 | 5.51 | 2.48 | 35.2 | 27.6 | .01 |
| 400 | 10.36 | 19.31 | 34.88 | .22 | 26.82 | 123.9 | 5.86 | 2.33 | 24.2 | 36.9 | .02 |
| 566 | 7.18 | 19.19 | 34.67 | .93 | 27.15 | 92.2 | 5.62 | 2.58 | 43.8 | 41.4 | .01 |

INTERPOLATED AND COMPUTED VALUES AT STANDARD DEPTHS

| Z (m) | T (°C) | Cl (‰) | S (‰) | $\sigma_T$ (gm/L) | $\delta_T$ (cl/T) | $\delta$ (cl/T) | $\Delta D_{Z/0}$ (dyn m) | $\Delta D_{Z/Z\,MAX}$ (dyn m) | $Q_Z$ (m-dynm) |
|---|---|---|---|---|---|---|---|---|---|
| 0 | 23.40 | 19.29 | 34.85 | 23.72 | 418.3 | 418.4 | 0 | 1.047 | 245.7 |
| 10 | 23.21 | 19.31 | 34.88 | 23.81 | 410.4 | 410.9 | .041 | 1.006 | 235.4 |
| 20 | 22.97 | 19.34 | 34.93 | 23.91 | 400.5 | 401.4 | .082 | .965 | 225.6 |
| 30 | 22.66 | 19.37 | 34.99 | 24.04 | 387.7 | 389.0 | .122 | .926 | 216.1 |
| 50 | 21.68 | 19.48 | 35.19 | 24.47 | 346.9 | 348.9 | .195 | .852 | 198.4 |
| 75 | 18.71 | 19.49 | 35.21 | 25.27 | 270.7 | 273.3 | .273 | .774 | 178.0 |
| 100 | 15.26 | 19.47 | 35.17 | 26.06 | 195.3 | 198.4 | .332 | .715 | 159.4 |
| 150 | 13.63 | 19.41 | 35.06 | 26.33 | 170.0 | 174.3 | .425 | .622 | 126.0 |
| 200 | 13.24 | 19.38 | 35.01 | 26.37 | 166.3 | 171.8 | .512 | .535 | 97.1 |
| 250 | 12.75 | 19.38 | 35.02 | 26.47 | 156.4 | 163.1 | .596 | .452 | 72.4 |
| 300 | 12.32 | 19.39 | 35.02 | 26.56 | 148.0 | 155.8 | .675 | .372 | 51.8 |
| 400 | 10.36 | 19.31 | 34.88 | 26.82 | 123.9 | 132.9 | .820 | .228 | 21.8 |
| 500 | 8.32 | 19.22 | 34.73 | 27.03 | 103.5 | 113.0 | .943 | .105 | 5.2 |
| 600 | 6.65 | 19.18 | 34.65 | 27.21 | 86.9 | 96.2 | 1.047 | 0 | 0 |

| STATION | DATE | TIME | LATITUDE | LONGITUDE | D |
|---|---|---|---|---|---|
| H 147 | DEC 24, 1963 | 1420-1510 | 02° 27.5'S | 088° 04.0'W | 19 |

OBSERVED AND COMPUTED VALUES AT OBSERVED DEPTHS

| Z | T | Cl | S | $O_2$ | $\sigma_T$ | $\delta_T$ | AOU | $PO_4$ | $NO_3$ | $SiO_4$ | $NO_2$ |
|---|---|---|---|---|---|---|---|---|---|---|---|
| (m) | (°C) | (‰) | (‰) | (ml/L) | (gm/L) | (cl/L) | (ml/L) | ——— ($\mu$g at./L) ——— | | | |
| 0 | 24.00 | 19.19 | 34.67 | 4.60 | 23.41 | 448.1 | .10 | .64 | 5.3 | 4.6 | .10 |
| 50 | 20.84 | 19.37 | 34.99 | 3.88 | 24.55 | 339.4 | 1.06 | 1.00 | 12.2 | 7.1 | .40 |
| 75 | 17.48 | 19.44 | 35.12 | 2.39 | 25.51 | 248.3 | 2.86 | 1.21 | 20.3 | 11.9 | .64 |
| 100 | 15.75 | 19.57 | 35.35 | 2.01 | 26.09 | 192.6 | 3.40 | 1.31 | 23.5 | 14.3 | .47 |
| 150 | 14.27 | 19.45 | 35.14 | 2.10 | 26.25 | 177.5 | 3.48 | 1.30 | 24.2 | 17.5 | .02 |
| 188 | 13.84 | 19.39 | 35.03 | 1.88 | 26.26 | 176.8 | 3.76 | 1.86 | 25.8 | 24.1 | .02 |
| 304 | 12.21 | 19.39 | 35.03 | 1.04 | 26.59 | 145.6 | 4.79 | 2.18 | 31.5 | -0 | .01 |
| 385 | 10.46 | 19.45 | 35.14 | .36 | 27.00 | 106.9 | 5.69 | 2.28 | 36.1 | 36.6 | .01 |
| 564 | 999.00 | 19.25 | 34.78 | .50 | 999.00 | 999.0 | 999.00 | -0 | -0 | -0 | -0 |

INTERPOLATED AND COMPUTED VALUES AT STANDARD DEPTHS

| Z (m) | T (°C) | Cl (‰) | S (‰) | $\sigma_T$ (gm/L) | $\delta_T$ (cl/T) | $\delta$ (cl/T) | $\Delta D_{Z/0}$ (dyn m) | $\Delta D_{Z/Z\,MAX}$ (dyn m) | $Q_Z$ (m-dynm) |
|---|---|---|---|---|---|---|---|---|---|
| 0 | 24.00 | 19.19 | 34.67 | 23.41 | 448.1 | 448.1 | 0 | .990 | 224.7 |
| 10 | 22.07 | 19.29 | 34.85 | 24.11 | 381.8 | 382.3 | .042 | .948 | 215.0 |
| 20 | 21.55 | 19.32 | 34.91 | 24.29 | 363.9 | 364.8 | .079 | .911 | 205.7 |
| 30 | 21.24 | 19.34 | 34.95 | 24.41 | 353.2 | 354.4 | .115 | .875 | 196.8 |
| 50 | 20.84 | 19.37 | 34.99 | 24.55 | 339.4 | 341.3 | .184 | .805 | 180.0 |
| 75 | 17.48 | 19.44 | 35.12 | 25.51 | 248.3 | 250.9 | .258 | .731 | 160.7 |
| 100 | 15.75 | 19.57 | 35.35 | 26.09 | 192.6 | 195.8 | .314 | .676 | 143.2 |
| 150 | 14.27 | 19.45 | 35.14 | 26.25 | 177.5 | 181.9 | .409 | .581 | 111.7 |
| 200 | 13.63 | 19.39 | 35.03 | 26.30 | 172.8 | 178.4 | .499 | .491 | 84.9 |
| 250 | 12.87 | 19.39 | 35.02 | 26.45 | 158.3 | 165.0 | .585 | .405 | 62.5 |
| 300 | 12.25 | 19.39 | 35.03 | 26.58 | 146.5 | 154.2 | .664 | .325 | 44.3 |
| 400 | 9.98 | 19.41 | 35.07 | 27.03 | 104.0 | 112.8 | .798 | .192 | 18.4 |
| 500 | 7.20 | 19.23 | 34.74 | 27.21 | 87.0 | 95.4 | .902 | .088 | 4.4 |
| 600 | 4.92 | 19.13 | 34.56 | 27.35 | 73.1 | 80.3 | .990 | 0 | 0 |

H 148

| STATION | DATE | TIME | LATITUDE | LONGITUDE | D |
|---|---|---|---|---|---|
| H 148 | DEC 24, 1963 | 2210-2255 | 01° 35.2'S | 087° 17.7'W | |

OBSERVED AND COMPUTED VALUES AT OBSERVED DEPTHS

| Z (m) | T (°C) | Cl (‰) | S (‰) | $O_2$ (ml/L) | $\sigma_T$ (gm/L) | $\delta_T$ (cl/L) | AOU (ml/L) | $PO_4$ (µg at./L) | $NO_3$ (µg at./L) | $SiO_4$ (µg at./L) | $NO_2$ (µg at./L) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 0 | 24.20 | 18.85 | 34.05 | 4.72 | 22.89 | 498.1 | -.02 | .49 | 3.1 | 3.7 | .06 |
| 47 | 20.81 | 19.39 | 35.03 | 3.71 | 24.59 | 336.0 | 1.24 | 1.06 | 12.9 | 7.0 | .51 |
| 70 | 18.96 | 19.47 | 35.17 | 2.70 | 25.18 | 279.3 | 2.40 | 1.10 | 18.4 | 10.0 | 1.00 |
| 94 | 17.37 | 19.45 | 35.14 | 2.34 | 25.55 | 244.4 | 2.92 | 1.48 | 20.5 | 12.1 | .38 |
| 141 | 14.89 | 19.59 | 35.39 | 2.13 | 26.31 | 171.7 | 3.38 | 1.64 | 23.5 | 16.1 | .01 |
| 223 | 14.02 | 19.42 | 35.08 | 1.98 | 26.27 | 176.4 | 3.63 | -0 | -0 | -0 | -0 |
| 308 | 12.03 | 19.33 | 34.92 | .38 | 26.54 | 150.3 | 5.48 | 2.46 | 35.4 | 29.1 | .01 |
| 401 | 10.11 | 19.28 | 34.83 | .35 | 26.82 | 123.7 | 5.76 | 2.74 | 39.1 | 38.0 | .01 |
| 598 | 7.45 | 19.20 | 34.69 | 1.44 | 27.13 | 94.5 | 5.07 | 2.54 | 40.5 | 45.0 | .01 |

INTERPOLATED AND COMPUTED VALUES AT STANDARD DEPTHS

| Z (m) | T (°C) | Cl (‰) | S (‰) | $\sigma_T$ (gm/L) | $\delta_T$ (cl/T) | $\delta$ (cl/T) | $\Delta D_{Z/O}$ (dyn m) | $\Delta D_{Z/Z\,MAX}$ (dyn m) | $Q_Z$ (m-dynm) |
|---|---|---|---|---|---|---|---|---|---|
| 0 | 24.20 | 18.85 | 34.05 | 22.89 | 498.1 | 498.2 | 0 | 1.102 | 255.5 |
| 10 | 23.80 | 18.91 | 34.16 | 23.09 | 478.8 | 479.3 | .049 | 1.053 | 244.7 |
| 20 | 23.28 | 18.99 | 34.31 | 23.35 | 454.3 | 455.1 | .096 | 1.007 | 234.4 |
| 30 | 22.61 | 19.09 | 34.50 | 23.68 | 422.1 | 423.3 | .140 | .963 | 224.6 |
| 50 | 20.59 | 19.40 | 35.05 | 24.66 | 329.0 | 330.9 | .215 | .887 | 206.1 |
| 75 | 18.59 | 19.46 | 35.16 | 25.27 | 271.2 | 273.8 | .291 | .812 | 184.9 |
| 100 | 16.99 | 19.47 | 35.17 | 25.66 | 233.4 | 236.7 | .354 | .748 | 165.4 |
| 150 | 14.77 | 19.57 | 35.35 | 26.31 | 172.4 | 176.9 | .458 | .644 | 130.6 |
| 200 | 14.23 | 19.46 | 35.15 | 26.28 | 175.3 | 181.1 | .547 | .555 | 100.6 |
| 250 | 13.32 | 19.38 | 35.02 | 26.36 | 167.2 | 174.1 | .636 | .466 | 75.1 |
| 300 | 12.19 | 19.34 | 34.93 | 26.52 | 152.4 | 160.1 | .720 | .383 | 53.8 |
| 400 | 10.13 | 19.28 | 34.83 | 26.82 | 124.0 | 132.9 | .866 | .236 | 22.9 |
| 500 | 8.64 | 19.23 | 34.74 | 26.99 | 107.6 | 117.4 | .991 | .111 | 5.5 |
| 600 | 7.43 | 19.20 | 34.68 | 27.13 | 94.2 | 104.5 | 1.102 | 0 | 0 |

H 149

| STATION | DATE | TIME | LATITUDE | LONGITUDE | D |
|---|---|---|---|---|---|
| H 149 | DEC 25, 1963 | 0600-0637 | 00° 33.4'S | 086° 24.5'W | 17 |

OBSERVED AND COMPUTED VALUES AT OBSERVED DEPTHS

| Z (m) | T (°C) | Cl (‰) | S (‰) | $O_2$ (ml/L) | $\sigma_T$ (gm/L) | $\delta_T$ (cl/L) | AOU (ml/L) | $PO_4$ (µg at./L) | $NO_3$ (µg at./L) | $SiO_4$ (µg at./L) | $NO_2$ (µg at./L) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 0 | 24.80 | 18.60 | 33.60 | 4.64 | 22.37 | 547.7 | .03 | .23 | 1.5 | 2.5 | .06 |
| 49 | 21.00 | 19.35 | 34.96 | 3.99 | 24.48 | 346.1 | .94 | .91 | 11.5 | 5.9 | .30 |
| 73 | 17.90 | 19.40 | 35.05 | 2.53 | 25.35 | 263.3 | 2.68 | 1.06 | 20.1 | 11.1 | .93 |
| 97 | 16.49 | 19.42 | 35.08 | 2.38 | 25.72 | 228.5 | 2.97 | 1.39 | 20.5 | 11.1 | .93 |
| 146 | 15.45 | 19.40 | 35.05 | 2.25 | 25.93 | 208.6 | 3.21 | 1.51 | 23.8 | 15.0 | .03 |
| 200 | 14.74 | 19.40 | 35.05 | 2.06 | 26.08 | 193.7 | 3.47 | 1.36 | 24.8 | 16.4 | .01 |
| 300 | 12.47 | 19.34 | 34.94 | .71 | 26.47 | 157.0 | 5.09 | 2.27 | 33.7 | 25.9 | .01 |
| 399 | 10.56 | 19.29 | 34.85 | .28 | 26.76 | 129.9 | 5.77 | 2.09 | 39.0 | 35.5 | .01 |
| 574 | 6.95 | 19.21 | 34.70 | .93 | 27.21 | 86.4 | 5.65 | 2.71 | 40.2 | 45.9 | .02 |

INTERPOLATED AND COMPUTED VALUES AT STANDARD DEPTHS

| Z (m) | T (°C) | Cl (‰) | S (‰) | $\sigma_T$ (gm/L) | $\delta_T$ (cl/T) | $\delta$ (cl/T) | $\Delta D_{Z/O}$ (dyn m) | $\Delta D_{Z/Z\,MAX}$ (dyn m) | $Q_Z$ (m-dynm) |
|---|---|---|---|---|---|---|---|---|---|
| 0 | 24.80 | 18.60 | 33.60 | 22.37 | 547.7 | 547.8 | 0 | 1.144 | 258.0 |
| 10 | 24.37 | 18.68 | 33.75 | 22.61 | 524.8 | 525.3 | .054 | 1.091 | 246.8 |
| 20 | 23.83 | 18.78 | 33.94 | 22.91 | 496.0 | 496.9 | .105 | 1.040 | 236.1 |
| 30 | 23.12 | 18.92 | 34.18 | 23.30 | 458.8 | 460.0 | .153 | .992 | 226.0 |
| 50 | 20.89 | 19.35 | 34.96 | 24.51 | 343.0 | 344.9 | .233 | .911 | 206.9 |
| 75 | 17.77 | 19.40 | 35.05 | 25.38 | 260.0 | 262.6 | .309 | .835 | 185.1 |
| 100 | 16.41 | 19.42 | 35.08 | 25.73 | 227.1 | 230.3 | .371 | .774 | 165.0 |
| 150 | 15.39 | 19.40 | 35.05 | 25.94 | 207.3 | 211.9 | .481 | .663 | 129.1 |
| 200 | 14.74 | 19.40 | 35.05 | 26.08 | 193.7 | 199.6 | .584 | .560 | 98.5 |
| 250 | 13.49 | 19.36 | 34.98 | 26.29 | 173.5 | 180.5 | .679 | .465 | 72.9 |
| 300 | 12.47 | 19.34 | 34.94 | 26.47 | 157.0 | 164.9 | .765 | .379 | 51.8 |
| 400 | 10.54 | 19.29 | 34.85 | 26.76 | 129.6 | 138.8 | .917 | .227 | 21.5 |
| 500 | 8.32 | 19.23 | 34.74 | 27.04 | 102.9 | 112.4 | 1.043 | .101 | 5.1 |
| 600 | 6.51 | 19.21 | 34.70 | 27.27 | 81.2 | 90.4 | 1.144 | 0 | 0 |

| STATION | DATE | TIME | LATITUDE | LONGITUDE | D |
|---|---|---|---|---|---|
| H 150 | DEC 25, 1963 | 1420-1510 | 00° 26.5'N | 085° 30.0'W | 16 |

OBSERVED AND COMPUTED VALUES AT OBSERVED DEPTHS

| Z (m) | T (°C) | Cl (‰) | S (‰) | $O_2$ (ml/L) | $\sigma_T$ (gm/L) | $\delta_T$ (cl/L) | AOU (ml/L) | $PO_4$ | $NO_3$ | $SiO_4$ | $NO_2$ |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | (μg at./L) | | | |
| 0 | 25.60 | 18.35 | 33.15 | 4.56 | 21.79 | 603.5 | .07 | .21 | .5 | 1.8 | .02 |
| 48 | 20.21 | 19.19 | 34.67 | 3.54 | 24.47 | 346.9 | 1.47 | .74 | 12.8 | 7.4 | .36 |
| 72 | 18.51 | 19.33 | 34.92 | 2.87 | 25.10 | 286.8 | 2.29 | .99 | 17.5 | 10.1 | .80 |
| 96 | 16.36 | 19.36 | 34.97 | 2.25 | 25.66 | 233.6 | 3.11 | 1.47 | 22.6 | 13.4 | .13 |
| 144 | 14.87 | 19.37 | 34.99 | 1.96 | 26.01 | 200.3 | 3.56 | 1.22 | 24.6 | 16.2 | .02 |
| 198 | 14.37 | 19.36 | 34.97 | 2.17 | 26.11 | 191.4 | 3.41 | 1.63 | 24.6 | 16.5 | .01 |
| 297 | 12.65 | 19.30 | 34.87 | 1.16 | 26.38 | 165.7 | 4.62 | 1.59 | 31.8 | 23.9 | .01 |
| 392 | 10.51 | 19.24 | 34.76 | .30 | 26.69 | 135.7 | 5.76 | 2.10 | 38.4 | 36.1 | .01 |
| 575 | 7.65 | 19.20 | 34.69 | .74 | 27.10 | 97.2 | 5.74 | 1.91 | 30.9 | 32.0 | -0 |

INTERPOLATED AND COMPUTED VALUES AT STANDARD DEPTHS

| Z (m) | T (°C) | Cl (‰) | S (‰) | $\sigma_T$ (gm/L) | $\delta_T$ (cl/T) | $\delta$ (cl/T) | $\Delta D_{Z/0}$ (dyn m) | $\Delta D_{Z/Z\,MAX}$ (dyn m) | $Q_Z$ (m-dynm) |
|---|---|---|---|---|---|---|---|---|---|
| 0 | 25.60 | 18.35 | 33.15 | 21.79 | 603.5 | 603.6 | 0 | 1.176 | 269.2 |
| 10 | 24.89 | 18.45 | 33.33 | 22.14 | 569.7 | 570.2 | .059 | 1.117 | 257.7 |
| 20 | 23.68 | 18.63 | 33.66 | 22.74 | 511.8 | 512.7 | .113 | 1.063 | 246.8 |
| 30 | 22.04 | 18.89 | 34.12 | 23.56 | 434.2 | 435.4 | .160 | 1.015 | 236.4 |
| 50 | 20.04 | 19.20 | 34.69 | 24.53 | 340.9 | 342.7 | .238 | .938 | 216.9 |
| 75 | 18.21 | 19.33 | 34.92 | 25.18 | 279.3 | 281.9 | .316 | .860 | 194.4 |
| 100 | 16.21 | 19.36 | 34.97 | 25.70 | 230.2 | 233.5 | .381 | .795 | 173.7 |
| 150 | 14.81 | 19.37 | 34.99 | 26.02 | 199.2 | 203.7 | .490 | .686 | 136.7 |
| 200 | 14.33 | 19.36 | 34.97 | 26.11 | 190.8 | 196.6 | .590 | .586 | 104.9 |
| 250 | 13.38 | 19.32 | 34.91 | 26.26 | 176.6 | 183.6 | .685 | .491 | 78.0 |
| 300 | 12.57 | 19.30 | 34.86 | 26.39 | 164.6 | 172.5 | .774 | .402 | 55.7 |
| 400 | 10.36 | 19.24 | 34.75 | 26.71 | 133.7 | 142.7 | .932 | .244 | 23.4 |
| 500 | 8.69 | 19.21 | 34.70 | 26.95 | 111.3 | 121.1 | 1.064 | .112 | 5.6 |
| 600 | 7.33 | 19.20 | 34.68 | 27.14 | 93.0 | 103.1 | 1.176 | 0 | 0 |

| STATION | DATE | TIME | LATITUDE | LONGITUDE | D |
|---|---|---|---|---|---|
| H 151 | DEC 25, 1963 | 2210-2245 | 01° 23.1'N | 084° 42.0'W | |

OBSERVED AND COMPUTED VALUES AT OBSERVED DEPTHS

| Z (m) | T (°C) | Cl (‰) | S (‰) | $O_2$ (ml/L) | $\sigma_T$ (gm/L) | $\delta_T$ (cl/L) | AOU (ml/L) | $PO_4$ | $NO_3$ | $SiO_4$ | $NO_2$ |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | (μg at./L) | | | |
| 0 | 25.20 | 18.37 | 33.19 | 4.65 | 21.94 | 589.2 | .01 | .22 | 1.3 | 2.5 | .05 |
| 44 | 20.44 | 19.13 | 34.56 | 3.45 | 24.33 | 360.5 | 1.54 | .69 | 12.6 | 7.1 | .27 |
| 66 | 18.14 | 19.36 | 34.97 | 2.32 | 25.24 | 274.1 | 2.87 | 1.16 | 20.3 | 10.5 | .52 |
| 88 | 16.62 | 19.39 | 35.03 | 2.15 | 25.64 | 235.4 | 3.19 | 1.17 | 22.2 | 12.9 | .47 |
| 132 | 15.44 | 19.42 | 35.08 | 1.97 | 25.96 | 205.7 | 3.49 | 1.19 | 23.5 | 14.9 | .02 |
| 278 | 13.04 | 19.35 | 34.96 | 1.29 | 26.37 | 166.5 | 4.44 | 1.93 | 36.4 | 33.3 | .01 |
| 320 | 11.19 | 19.29 | 34.85 | .37 | 26.64 | 140.6 | 5.60 | 2.08 | 36.0 | 33.3 | .01 |
| 460 | 8.62 | 19.23 | 34.74 | .34 | 26.99 | 107.2 | 5.99 | 2.46 | 40.8 | 42.8 | .01 |
| 630 | 6.72 | 19.22 | 34.72 | .91 | 27.26 | 82.1 | 5.71 | 2.38 | 38.7 | 42.0 | .04 |

INTERPOLATED AND COMPUTED VALUES AT STANDARD DEPTHS

| Z (m) | T (°C) | Cl (‰) | S (‰) | $\sigma_T$ (gm/L) | $\delta_T$ (cl/T) | $\delta$ (cl/T) | $\Delta D_{Z/0}$ (dyn m) | $\Delta D_{Z/Z\,MAX}$ (dyn m) | $Q_Z$ (m-dynm) |
|---|---|---|---|---|---|---|---|---|---|
| 0 | 25.20 | 18.37 | 33.19 | 21.93 | 589.2 | 589.3 | 0 | 1.117 | 250.8 |
| 10 | 24.50 | 18.47 | 33.37 | 22.29 | 555.6 | 556.1 | .057 | 1.060 | 239.9 |
| 20 | 23.22 | 18.67 | 33.73 | 22.93 | 493.9 | 494.8 | .110 | 1.007 | 229.5 |
| 30 | 21.76 | 18.91 | 34.15 | 23.66 | 424.0 | 425.3 | .156 | .961 | 219.7 |
| 50 | 19.72 | 19.20 | 34.68 | 24.61 | 333.4 | 335.2 | .232 | .885 | 201.2 |
| 75 | 17.47 | 19.37 | 35.00 | 25.42 | 256.9 | 259.5 | .306 | .811 | 180.0 |
| 100 | 16.25 | 19.40 | 35.04 | 25.74 | 226.0 | 229.3 | .367 | .750 | 160.5 |
| 150 | 15.03 | 19.40 | 35.06 | 26.03 | 199.0 | 203.6 | .476 | .642 | 125.7 |
| 200 | 14.10 | 19.38 | 35.00 | 26.19 | 183.8 | 189.6 | .574 | .543 | 96.1 |
| 250 | 13.38 | 19.36 | 34.97 | 26.31 | 172.1 | 179.0 | .666 | .451 | 71.2 |
| 300 | 12.04 | 19.31 | 34.89 | 26.52 | 152.5 | 160.2 | .751 | .366 | 50.8 |
| 400 | 9.61 | 19.25 | 34.77 | 26.86 | 120.1 | 128.6 | .895 | .222 | 21.4 |
| 500 | 8.12 | 19.22 | 34.73 | 27.06 | 100.5 | 109.8 | 1.014 | .103 | 5.1 |
| 600 | 7.01 | 19.22 | 34.72 | 27.22 | 86.0 | 95.8 | 1.117 | 0 | 0 |

| STATION | DATE | TIME | LATITUDE | LONGITUDE | D |
|---|---|---|---|---|---|
| H 152 | DEC 26, 1963 | 0600-0645 | 02° 22.9'N | 083° 51.9'W | |

OBSERVED AND COMPUTED VALUES AT OBSERVED DEPTHS

| Z (m) | T (°C) | Cl (‰) | S (‰) | $O_2$ (ml/L) | $\sigma_T$ (gm/L) | $\delta_T$ (cl/L) | AOU (ml/L) | $PO_4$ (μg at./L) | $NO_3$ (μg at./L) | $SiO_4$ (μg at./L) | $NO_2$ (μg at./L) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 0 | 26.20 | 18.03 | 32.57 | 4.50 | 21.17 | 662.9 | .10 | .22 | .5 | 1.6 | .01 |
| 50 | 19.42 | 19.14 | 34.58 | 2.84 | 24.61 | 333.8 | 2.24 | 1.02 | 16.5 | 8.5 | .33 |
| 75 | 16.51 | 19.39 | 35.03 | 2.03 | 25.67 | 232.9 | 3.32 | 1.55 | 23.1 | 13.3 | .12 |
| 100 | 15.62 | 19.40 | 35.05 | 2.15 | 25.89 | 212.2 | 3.29 | 1.34 | 23.2 | 14.9 | .02 |
| 150 | 14.79 | 19.38 | 35.01 | 1.78 | 26.04 | 197.4 | 3.75 | 1.43 | 25.6 | 16.8 | .02 |
| 220 | 13.92 | 19.37 | 34.99 | 1.76 | 26.22 | 181.0 | 3.87 | 1.49 | 27.0 | 19.0 | .01 |
| 316 | 12.23 | 19.36 | 34.97 | .55 | 26.54 | 150.0 | 5.28 | 1.95 | 34.3 | 27.3 | 0 |
| 410 | 9.44 | 19.23 | 34.74 | .21 | 26.86 | 119.7 | 6.00 | 2.82 | 40.0 | 42.1 | 0 |
| 601 | 7.16 | 19.21 | 34.70 | .55 | 27.18 | 89.2 | 6.00 | 3.00 | 34.4 | 52.0 | 0 |

INTERPOLATED AND COMPUTED VALUES AT STANDARD DEPTHS

H 152

| Z (m) | T (°C) | Cl (‰) | S (‰) | $\sigma_T$ (gm/L) | $\delta_T$ (cl/T) | $\delta$ (cl/T) | $\Delta D_{Z/0}$ (dyn m) | $\Delta D_{Z/Z\,MAX}$ (dyn m) | $Q_Z$ (m-dynm) |
|---|---|---|---|---|---|---|---|---|---|
| 0 | 26.20 | 18.03 | 32.57 | 21.17 | 662.9 | 663.0 | 0 | 1.135 | 254.1 |
| 10 | 25.35 | 18.15 | 32.80 | 21.60 | 621.7 | 622.2 | .064 | 1.071 | 243.1 |
| 20 | 23.94 | 18.37 | 33.19 | 22.31 | 553.2 | 554.0 | .123 | 1.012 | 232.7 |
| 30 | 21.92 | 18.70 | 33.78 | 23.33 | 455.4 | 456.6 | .174 | .961 | 222.8 |
| 50 | 19.42 | 19.14 | 34.58 | 24.61 | 333.8 | 335.6 | .253 | .882 | 204.4 |
| 75 | 16.51 | 19.39 | 35.03 | 25.67 | 232.9 | 235.4 | .324 | .811 | 183.2 |
| 100 | 15.62 | 19.40 | 35.05 | 25.89 | 212.2 | 215.4 | .381 | .755 | 163.6 |
| 150 | 14.79 | 19.38 | 35.01 | 26.04 | 197.4 | 201.9 | .485 | .650 | 128.5 |
| 200 | 14.14 | 19.37 | 35.00 | 26.17 | 185.1 | 190.9 | .583 | .552 | 98.4 |
| 250 | 13.32 | 19.36 | 34.98 | 26.33 | 170.1 | 177.0 | .675 | .460 | 73.1 |
| 300 | 12.47 | 19.36 | 34.97 | 26.50 | 154.4 | 162.3 | .760 | .375 | 52.3 |
| 400 | 9.70 | 19.24 | 34.76 | 26.83 | 122.6 | 131.2 | .907 | .229 | 22.1 |
| 500 | 8.26 | 19.21 | 34.71 | 27.03 | 103.9 | 113.3 | 1.029 | .106 | 5.3 |
| 600 | 7.17 | 19.21 | 34.70 | 27.18 | 89.4 | 99.3 | 1.135 | 0 | 0 |

| STATION | DATE | TIME | LATITUDE | LONGITUDE | D |
|---|---|---|---|---|---|
| H 153 | DEC 26, 1963 | 1420-1500 | 03° 42.5'N | 082° 45.0'W | 27 |

OBSERVED AND COMPUTED VALUES AT OBSERVED DEPTHS

| Z (m) | T (°C) | Cl (‰) | S (‰) | $O_2$ (ml/L) | $\sigma_T$ (gm/L) | $\delta_T$ (cl/L) | AOU (ml/L) | $PO_4$ (μg at./L) | $NO_3$ (μg at./L) | $SiO_4$ (μg at./L) | $NO_2$ (μg at./L) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 0 | 27.20 | 18.04 | 32.59 | 4.48 | 20.87 | 691.7 | .05 | .25 | .6 | 1.7 | .01 |
| 50 | 22.59 | 18.87 | 34.09 | 3.57 | 23.38 | 450.9 | 1.26 | -0 | -0 | -0 | -0 |
| 74 | 16.92 | 19.27 | 34.81 | 1.88 | 25.41 | 257.9 | 3.43 | 1.66 | 24.5 | 12.7 | .07 |
| 99 | 16.07 | 19.32 | 34.90 | 2.15 | 25.68 | 232.5 | 3.25 | 1.38 | 24.6 | 14.6 | .24 |
| 149 | 14.46 | 19.28 | 34.83 | 1.59 | 25.98 | 203.8 | 3.98 | 1.46 | 25.0 | 17.3 | .01 |
| 243 | 13.22 | 19.26 | 34.79 | 1.04 | 26.21 | 181.9 | 4.68 | 1.68 | 30.4 | 23.1 | .01 |
| 339 | 11.08 | 19.22 | 34.72 | .26 | 26.56 | 148.1 | 5.73 | 2.25 | 36.8 | 34.4 | 0 |
| 431 | 8.96 | 19.17 | 34.63 | .23 | 26.86 | 120.3 | 6.05 | 2.56 | 41.3 | 46.6 | .01 |
| 614 | 7.17 | 19.08 | 34.47 | .56 | 27.00 | 106.8 | 6.00 | 2.94 | 43.0 | 53.0 | 0 |

H 153

INTERPOLATED AND COMPUTED VALUES AT STANDARD DEPTHS

| Z (m) | T (°C) | Cl (‰) | S (‰) | $\sigma_T$ (gm/L) | $\delta_T$ (cl/T) | $\delta$ (cl/T) | $\Delta D_{Z/0}$ (dyn m) | $\Delta D_{Z/Z\,MAX}$ (dyn m) | $Q_Z$ (m-dynm) |
|---|---|---|---|---|---|---|---|---|---|
| 0 | 27.20 | 18.04 | 32.59 | 20.87 | 691.7 | 691.8 | 0 | 1.249 | 274.1 |
| 10 | 26.69 | 18.13 | 32.75 | 21.14 | 665.0 | 665.5 | .068 | 1.181 | 262.0 |
| 20 | 26.05 | 18.24 | 32.95 | 21.49 | 631.5 | 632.4 | .133 | 1.116 | 250.5 |
| 30 | 25.22 | 18.38 | 33.21 | 21.94 | 588.5 | 589.8 | .194 | 1.055 | 239.6 |
| 50 | 22.59 | 18.87 | 34.09 | 23.38 | 450.9 | 452.9 | .298 | .951 | 219.6 |
| 75 | 16.88 | 19.27 | 34.82 | 25.42 | 256.7 | 259.2 | .387 | .862 | 196.9 |
| 100 | 16.03 | 19.32 | 34.90 | 25.68 | 231.8 | 235.0 | .449 | .800 | 176.1 |
| 150 | 14.44 | 19.28 | 34.83 | 25.98 | 203.5 | 207.9 | .560 | .689 | 138.9 |
| 200 | 13.71 | 19.27 | 34.81 | 26.11 | 190.6 | 196.3 | .661 | .588 | 106.9 |
| 250 | 13.04 | 19.26 | 34.79 | 26.24 | 179.0 | 185.8 | .756 | .493 | 79.9 |
| 300 | 11.87 | 19.23 | 34.74 | 26.43 | 160.5 | 168.0 | .845 | .404 | 57.5 |
| 400 | 9.62 | 19.18 | 34.65 | 26.76 | 128.9 | 137.5 | .997 | .252 | 24.7 |
| 500 | 8.21 | 19.13 | 34.56 | 26.91 | 114.7 | 124.0 | 1.128 | .121 | 6.0 |
| 600 | 7.29 | 19.08 | 34.48 | 26.99 | 107.7 | 117.8 | 1.249 | 0 | 0 |

| STATION | DATE | TIME | LATITUDE | LONGITUDE | D |
|---|---|---|---|---|---|
| H 154 | JAN 4, 1964 | 1220-1325 | 05° 37.4'N | 081° 50.6'W | 15 |

OBSERVED AND COMPUTED VALUES AT OBSERVED DEPTHS

| Z (m) | T (°C) | Cl (‰) | S (‰) | $O_2$ (ml/L) | $\sigma_T$ (gm/L) | $\delta_T$ (cl/L) | AOU (ml/L) | $PO_4$ (µg at./L) | $NO_3$ (µg at./L) | $SiO_4$ (µg at./L) | $NO_2$ (µg at./L) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 0 | 28.20 | 16.54 | 29.88 | 4.66 | 18.52 | 917.7 | -.12 | -0 | -0 | -0 | -0 |
| 48 | 24.53 | 18.47 | 33.37 | 4.21 | 22.27 | 556.9 | .49 | -0 | -0 | -0 | -0 |
| 72 | 19.10 | 19.15 | 34.60 | 2.47 | 24.71 | 324.6 | 2.64 | -0 | -0 | -0 | -0 |
| 96 | 15.74 | 19.27 | 34.81 | 1.29 | 25.68 | 231.9 | 4.15 | -0 | -0 | -0 | -0 |
| 144 | 14.52 | 19.29 | 34.85 | .88 | 25.98 | 203.7 | 4.69 | -0 | -0 | -0 | -0 |
| 223 | 13.42 | 19.30 | 34.87 | .66 | 26.22 | 180.4 | 5.03 | -0 | -0 | -0 | -0 |
| 304 | 11.74 | 19.24 | 34.76 | .29 | 26.47 | 157.0 | 5.61 | -0 | -0 | -0 | -0 |
| 399 | 9.67 | 19.18 | 34.65 | .16 | 26.75 | 130.0 | 6.02 | -0 | -0 | -0 | -0 |
| 587 | 7.00 | 19.14 | 34.58 | .41 | 27.11 | 96.5 | 6.17 | -0 | -0 | -0 | -0 |

INTERPOLATED AND COMPUTED VALUES AT STANDARD DEPTHS

| Z (m) | T (°C) | Cl (‰) | S (‰) | $\sigma_T$ (gm/L) | $\delta_T$ (cl/T) | $\delta$ (cl/T) | $\Delta D_{Z/0}$ (dyn m) | $\Delta D_{Z/Z\,MAX}$ (dyn m) | $Q_Z$ (m-dyn m) |
|---|---|---|---|---|---|---|---|---|---|
| 0 | 28.20 | 16.54 | 29.88 | 18.52 | 917.7 | 917.8 | 0 | 1.339 | 270.0 |
| 10 | 27.77 | 16.76 | 30.28 | 18.95 | 875.7 | 876.2 | .090 | 1.249 | 257.0 |
| 20 | 27.23 | 17.04 | 30.79 | 19.50 | 822.7 | 823.6 | .175 | 1.164 | 244.9 |
| 30 | 26.53 | 17.41 | 31.45 | 20.22 | 753.7 | 755.0 | .254 | 1.085 | 233.7 |
| 50 | 24.16 | 18.52 | 33.46 | 22.45 | 539.6 | 541.6 | .383 | .956 | 213.3 |
| 75 | 18.62 | 19.16 | 34.62 | 24.84 | 311.5 | 314.2 | .490 | .849 | 190.7 |
| 100 | 15.62 | 19.27 | 34.81 | 25.71 | 229.1 | 232.2 | .559 | .781 | 170.4 |
| 150 | 14.42 | 19.29 | 34.85 | 26.00 | 201.5 | 206.0 | .668 | .671 | 134.1 |
| 200 | 13.69 | 19.30 | 34.86 | 26.16 | 186.2 | 191.9 | .768 | .572 | 103.0 |
| 250 | 12.80 | 19.28 | 34.82 | 26.31 | 171.8 | 178.5 | .860 | .479 | 76.7 |
| 300 | 11.81 | 19.24 | 34.76 | 26.46 | 158.0 | 165.6 | .946 | .393 | 54.9 |
| 400 | 9.65 | 19.18 | 34.65 | 26.76 | 129.8 | 138.4 | 1.098 | .241 | 23.2 |
| 500 | 8.11 | 19.15 | 34.60 | 26.96 | 110.4 | 119.7 | 1.227 | .112 | 5.6 |
| 600 | 6.85 | 19.14 | 34.58 | 27.13 | 94.6 | 104.2 | 1.339 | 0 | 0 |

| STATION | DATE | TIME | LATITUDE | LONGITUDE | D |
|---|---|---|---|---|---|
| H 160 | JAN 5, 1964 | 1220-1308 | 03° 14.7'N | 085° 05.7'W | 23 |

OBSERVED AND COMPUTED VALUES AT OBSERVED DEPTHS

| Z (m) | T (°C) | Cl (‰) | S (‰) | $O_2$ (ml/L) | $\sigma_T$ (gm/L) | $\delta_T$ (cl/L) | AOU (ml/L) | $PO_4$ (µg at./L) | $NO_3$ (µg at./L) | $SiO_4$ (µg at./L) | $NO_2$ (µg at./L) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 0 | 26.30 | 18.17 | 32.83 | 4.64 | 21.33 | 647.6 | -.05 | -0 | -0 | -0 | -0 |
| 50 | 23.27 | 18.56 | 33.53 | 4.36 | 22.77 | 509.9 | .43 | -0 | -0 | -0 | -0 |
| 74 | 16.48 | 19.33 | 34.92 | 1.69 | 25.59 | 240.2 | 3.66 | -0 | -0 | -0 | -0 |
| 99 | 15.66 | 19.31 | 34.88 | 2.09 | 25.75 | 224.9 | 3.35 | -0 | -0 | -0 | -0 |
| 149 | 14.36 | 19.32 | 34.90 | 1.62 | 26.05 | 196.5 | 3.96 | -0 | -0 | -0 | -0 |
| 200 | 13.78 | 19.29 | 34.85 | 1.22 | 26.13 | 188.8 | 4.43 | -0 | -0 | -0 | -0 |
| 295 | 12.62 | 19.26 | 34.79 | .54 | 26.33 | 170.5 | 5.25 | -0 | -0 | -0 | -0 |
| 391 | 10.22 | 19.21 | 34.70 | .30 | 26.70 | 134.9 | 5.80 | -0 | -0 | -0 | -0 |
| 574 | 7.30 | 19.16 | 34.61 | .69 | 27.09 | 97.8 | 5.84 | -0 | -0 | -0 | -0 |

INTERPOLATED AND COMPUTED VALUES AT STANDARD DEPTHS

| Z (m) | T (°C) | Cl (‰) | S (‰) | $\sigma_T$ (gm/L) | $\delta_T$ (cl/T) | $\delta$ (cl/T) | $\Delta D_{Z/0}$ (dyn m) | $\Delta D_{Z/Z\,MAX}$ (dyn m) | $Q_Z$ (m-dyn m) |
|---|---|---|---|---|---|---|---|---|---|
| 0 | 26.30 | 18.17 | 32.83 | 21.32 | 647.6 | 647.7 | 0 | 1.243 | 271.2 |
| 10 | 25.96 | 18.21 | 32.90 | 21.48 | 632.3 | 632.8 | .064 | 1.179 | 259.1 |
| 20 | 25.54 | 18.26 | 32.99 | 21.68 | 613.2 | 614.1 | .126 | 1.116 | 247.6 |
| 30 | 25.00 | 18.33 | 33.12 | 21.94 | 588.6 | 589.9 | .187 | 1.056 | 236.8 |
| 50 | 23.27 | 18.56 | 33.53 | 22.76 | 509.9 | 511.9 | .297 | .946 | 216.8 |
| 75 | 16.44 | 19.33 | 34.92 | 25.60 | 239.5 | 241.9 | .391 | .852 | 194.3 |
| 100 | 15.63 | 19.31 | 34.88 | 25.76 | 224.2 | 227.4 | .450 | .793 | 173.7 |
| 150 | 14.35 | 19.32 | 34.90 | 26.05 | 196.3 | 200.7 | .557 | .686 | 136.8 |
| 200 | 13.78 | 19.29 | 34.85 | 26.13 | 188.8 | 194.5 | .655 | .587 | 104.9 |
| 250 | 13.11 | 19.27 | 34.81 | 26.24 | 178.3 | 185.1 | .750 | .492 | 78.0 |
| 300 | 12.48 | 19.26 | 34.79 | 26.35 | 168.3 | 176.2 | .841 | .402 | 55.6 |
| 400 | 10.05 | 19.20 | 34.69 | 26.72 | 132.7 | 141.5 | 1.000 | .243 | 23.3 |
| 500 | 8.35 | 19.17 | 34.63 | 26.95 | 111.2 | 120.6 | 1.131 | .112 | 5.6 |
| 600 | 6.96 | 19.16 | 34.61 | 27.14 | 93.6 | 103.3 | 1.243 | 0 | 0 |

| STATION | DATE | TIME | LATITUDE | LONGITUDE | D |
|---|---|---|---|---|---|
| H 166 | JAN 6, 1964 | 1225-1313 | 00° 26.3'N | 087° 31.6'W | 20 |

OBSERVED AND COMPUTED VALUES AT OBSERVED DEPTHS

| Z (m) | T (°C) | Cl (‰) | S (‰) | $O_2$ (ml/L) | $\sigma_T$ (gm/L) | $\delta_T$ (cl/L) | AOU (ml/L) | $PO_4$ (μg at./L) | $NO_3$ (μg at./L) | $SiO_4$ (μg at./L) | $NO_2$ (μg at./L) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 0 | 25.80 | 18.68 | 33.75 | 4.60 | 22.17 | 566.5 | -.01 | -0 | -0 | -0 | -0 |
| 48 | 20.75 | 19.32 | 34.90 | 3.64 | 24.51 | 343.6 | 1.32 | -0 | -0 | -0 | -0 |
| 71 | 18.25 | 19.37 | 34.99 | 2.70 | 25.22 | 275.4 | 2.48 | -0 | -0 | -0 | -0 |
| 95 | 16.61 | 19.37 | 34.99 | 2.35 | 25.62 | 237.8 | 2.99 | -0 | -0 | -0 | -0 |
| 143 | 15.04 | 19.36 | 34.97 | 1.96 | 25.96 | 205.2 | 3.54 | -0 | -0 | -0 | -0 |
| 221 | 14.21 | 19.33 | 34.92 | 2.16 | 26.10 | 192.1 | 3.44 | -0 | -0 | -0 | -0 |
| 317 | 11.68 | 19.27 | 34.81 | .38 | 26.52 | 151.9 | 5.53 | -0 | -0 | -0 | -0 |
| 398 | 9.47 | 19.20 | 34.69 | .34 | 26.82 | 124.2 | 5.87 | -0 | -0 | -0 | -0 |
| 578 | 6.77 | 19.16 | 34.61 | .91 | 27.17 | 90.8 | 5.71 | -0 | -0 | -0 | -0 |

INTERPOLATED AND COMPUTED VALUES AT STANDARD DEPTHS

| Z (m) | T (°C) | Cl (‰) | S (‰) | $\sigma_T$ (gm/L) | $\delta_T$ (cl/T) | $\delta$ (cl/T) | $\Delta D_{Z/0}$ (dyn m) | $\Delta D_{Z/Z\,MAX}$ (dyn m) | $Q_Z$ (m-dynm) |
|---|---|---|---|---|---|---|---|---|---|
| 0 | 25.80 | 18.68 | 33.75 | 22.17 | 566.5 | 566.6 | 0 | 1.151 | 258.4 |
| 10 | 25.21 | 18.75 | 33.87 | 22.44 | 540.5 | 541.1 | .055 | 1.096 | 247.1 |
| 20 | 24.47 | 18.83 | 34.03 | 22.79 | 507.8 | 508.7 | .108 | 1.043 | 236.4 |
| 30 | 23.50 | 18.95 | 34.24 | 23.23 | 465.2 | 466.4 | .157 | .995 | 226.2 |
| 50 | 20.55 | 19.32 | 34.91 | 24.56 | 338.0 | 339.9 | .237 | .914 | 207.2 |
| 75 | 17.94 | 19.37 | 34.99 | 25.30 | 268.4 | 271.0 | .314 | .838 | 185.3 |
| 100 | 16.41 | 19.37 | 34.99 | 25.66 | 233.7 | 237.0 | .377 | .774 | 165.1 |
| 150 | 14.95 | 19.36 | 34.97 | 25.98 | 203.8 | 208.3 | .488 | .663 | 129.2 |
| 200 | 14.40 | 19.34 | 34.93 | 26.07 | 195.1 | 201.0 | .591 | .560 | 98.6 |
| 250 | 13.35 | 19.30 | 34.87 | 26.24 | 178.4 | 185.3 | .687 | .464 | 73.0 |
| 300 | 12.07 | 19.28 | 34.82 | 26.46 | 158.1 | 165.8 | .775 | .376 | 52.0 |
| 400 | 9.43 | 19.20 | 34.68 | 26.82 | 123.7 | 132.1 | .924 | .227 | 21.8 |
| 500 | 7.82 | 19.17 | 34.63 | 27.03 | 103.8 | 112.8 | 1.047 | .105 | 5.2 |
| 600 | 6.50 | 19.16 | 34.61 | 27.20 | 87.5 | 96.7 | 1.151 | 0 | 0 |

H 166

| STATION | DATE | TIME | LATITUDE | LONGITUDE | D |
|---|---|---|---|---|---|
| H 172 | JAN 7, 1964 | 1220-1304 | 02° 38.8'S | 090° 13.2'W | 20 |

OBSERVED AND COMPUTED VALUES AT OBSERVED DEPTHS

| Z (m) | T (°C) | Cl (‰) | S (‰) | $O_2$ (ml/L) | $\sigma_T$ (gm/L) | $\delta_T$ (cl/L) | AOU (ml/L) | $PO_4$ (μg at./L) | $NO_3$ (μg at./L) | $SiO_4$ (μg at./L) | $NO_2$ (μg at./L) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 0 | 24.00 | 19.26 | 34.79 | 4.72 | 23.51 | 439.0 | -.02 | -0 | -0 | -0 | -0 |
| 43 | 20.43 | 19.40 | 35.05 | 3.23 | 24.70 | 325.0 | 1.75 | -0 | -0 | -0 | -0 |
| 65 | 17.51 | 19.46 | 35.16 | 2.45 | 25.53 | 246.3 | 2.79 | -0 | -0 | -0 | -0 |
| 87 | 15.45 | 19.39 | 35.03 | 2.22 | 25.91 | 209.9 | 3.24 | -0 | -0 | -0 | -0 |
| 130 | 14.40 | 19.34 | 34.94 | 2.21 | 26.07 | 194.6 | 3.37 | -0 | -0 | -0 | -0 |
| 250 | 12.54 | 19.26 | 34.79 | .91 | 26.34 | 169.0 | 4.89 | -0 | -0 | -0 | -0 |
| 345 | 10.33 | 19.20 | 34.69 | .32 | 26.67 | 138.0 | 5.77 | -0 | -0 | -0 | -0 |
| 434 | 9.30 | 19.17 | 34.63 | .47 | 76.80 | 125.5 | 5.76 | -0 | -0 | -0 | -0 |
| 615 | 6.82 | 19.16 | 34.61 | .72 | 27.16 | 91.5 | 5.89 | -0 | -0 | -0 | -0 |

H 172

INTERPOLATED AND COMPUTED VALUES AT STANDARD DEPTHS

| Z (m) | T (°C) | Cl (‰) | S (‰) | $\sigma_T$ (gm/L) | $\delta_T$ (cl/T) | $\delta$ (cl/T) | $\Delta D_{Z/0}$ (dyn m) | $\Delta D_{Z/Z\,MAX}$ (dyn m) | $Q_Z$ (m-dynm) |
|---|---|---|---|---|---|---|---|---|---|
| 0 | 24.00 | 19.26 | 34.79 | 23.51 | 439.0 | 439.1 | 0 | 1.072 | 258.0 |
| 10 | 23.53 | 19.27 | 34.82 | 23.66 | 424.0 | 424.5 | .043 | 1.029 | 247.5 |
| 20 | 22.92 | 19.29 | 34.86 | 23.87 | 404.5 | 405.3 | .085 | .988 | 237.4 |
| 30 | 22.09 | 19.33 | 34.91 | 24.15 | 377.9 | 379.2 | .124 | .948 | 227.7 |
| 50 | 19.55 | 19.41 | 35.07 | 24.95 | 301.2 | 303.1 | .192 | .880 | 209.4 |
| 75 | 16.50 | 19.42 | 35.09 | 25.72 | 228.5 | 231.0 | .259 | .813 | 188.3 |
| 100 | 15.09 | 19.37 | 35.00 | 25.97 | 204.6 | 207.7 | .314 | .759 | 168.6 |
| 150 | 13.99 | 19.32 | 34.90 | 26.13 | 189.0 | 193.4 | .414 | .658 | 133.2 |
| 200 | 13.18 | 19.28 | 34.84 | 26.25 | 177.7 | 183.2 | .508 | .564 | 102.6 |
| 250 | 12.54 | 19.26 | 34.79 | 26.34 | 169.0 | 175.6 | .598 | .474 | 76.6 |
| 300 | 11.29 | 19.22 | 34.72 | 26.53 | 151.5 | 158.8 | .681 | .391 | 55.0 |
| 400 | 9.67 | 19.18 | 34.65 | 26.75 | 130.0 | 138.6 | .830 | .242 | 23.4 |
| 500 | 8.29 | 19.16 | 34.61 | 26.95 | 111.7 | 121.1 | .960 | .112 | 5.6 |
| 600 | 7.00 | 19.16 | 34.61 | 27.13 | 93.9 | 103.7 | 1.072 | 0 | 0 |

| STATION | DATE | TIME | LATITUDE | LONGITUDE | D |
|---|---|---|---|---|---|
| H 178 | JAN 8, 1964 | 1225-1308 | 05° 11.6'S | 093° 23.0'W | 17 |

OBSERVED AND COMPUTED VALUES AT OBSERVED DEPTHS

| Z | T | Cl | S | $O_2$ | $\sigma_T$ | $\delta_T$ | AOU | $PO_4$ | $NO_3$ | $SiO_4$ | $NO_2$ |
|---|---|---|---|---|---|---|---|---|---|---|---|
| (m) | (°C) | (‰) | (‰) | (ml/L) | (gm/L) | (cl/L) | (ml/L) | (µg at./L) | | | |
| 0 | 24.10 | 19.17 | 34.63 | 4.87 | 23.35 | 453.6 | -.18 | -0 | -0 | -0 | -0 |
| 44 | 22.13 | 19.18 | 34.65 | 4.69 | 23.94 | 398.1 | .16 | -0 | -0 | -0 | -0 |
| 66 | 22.42 | 19.23 | 34.74 | 4.87 | 23.92 | 399.3 | -.05 | -0 | -0 | -0 | -0 |
| 88 | 20.98 | 19.28 | 34.83 | 4.78 | 24.39 | 354.8 | .16 | -0 | -0 | -0 | -0 |
| 132 | 14.87 | 19.37 | 34.99 | 1.20 | 26.01 | 200.3 | 4.32 | -0 | -0 | -0 | -0 |
| 241 | 12.26 | 19.33 | 34.92 | .89 | 26.50 | 154.5 | 4.94 | -0 | -0 | -0 | -0 |
| 324 | 10.95 | 19.26 | 34.79 | .25 | 26.64 | 140.5 | 5.75 | -0 | -0 | -0 | -0 |
| 403 | 9.48 | 19.28 | 34.83 | .15 | 26.93 | 113.6 | 6.05 | -0 | -0 | -0 | -0 |
| 588 | 7.09 | 19.25 | 34.78 | .63 | 27.25 | 82.9 | 5.93 | -0 | -0 | -0 | -0 |

INTERPOLATED AND COMPUTED VALUES AT STANDARD DEPTHS

| Z | T | Cl | S | $\sigma_T$ | $\delta_T$ | $\delta$ | $\Delta D_{Z/0}$ | $\Delta D_{Z/Z\,MAX}$ | $Q_Z$ |
|---|---|---|---|---|---|---|---|---|---|
| (m) | (°C) | (‰) | (‰) | (gm/L) | (cl/T) | (cl/T) | (dyn m) | (dyn m) | (m-dyn m) |
| 0 | 24.10 | 19.17 | 34.63 | 23.35 | 453.6 | 453.7 | 0 | 1.134 | 245.0 |
| 10 | 23.85 | 19.17 | 34.63 | 23.43 | 446.4 | 446.9 | .045 | 1.089 | 233.9 |
| 20 | 23.52 | 19.17 | 34.63 | 23.52 | 437.2 | 438.1 | .089 | 1.045 | 223.2 |
| 30 | 23.08 | 19.17 | 34.64 | 23.65 | 424.9 | 426.1 | .132 | 1.001 | 213.0 |
| 50 | 22.21 | 19.19 | 34.68 | 23.93 | 398.4 | 400.4 | .215 | .919 | 193.8 |
| 75 | 21.92 | 19.25 | 34.77 | 24.08 | 383.8 | 386.7 | .314 | .820 | 172.0 |
| 100 | 19.53 | 19.29 | 34.84 | 24.78 | 317.4 | 321.0 | .402 | .732 | 152.6 |
| 150 | 14.32 | 19.36 | 34.97 | 26.11 | 190.6 | 195.0 | .531 | .603 | 119.3 |
| 200 | 13.07 | 19.34 | 34.93 | 26.34 | 168.7 | 174.2 | .623 | .511 | 91.4 |
| 250 | 12.10 | 19.32 | 34.90 | 26.51 | 152.8 | 159.2 | .707 | .427 | 68.0 |
| 300 | 11.29 | 19.28 | 34.82 | 26.60 | 144.1 | 151.4 | .784 | .350 | 48.5 |
| 400 | 9.53 | 19.28 | 34.83 | 26.92 | 114.6 | 123.1 | .922 | .212 | 20.4 |
| 500 | 8.12 | 19.26 | 34.79 | 27.11 | 96.1 | 105.4 | 1.036 | .098 | 4.9 |
| 600 | 6.96 | 19.25 | 34.78 | 27.27 | 81.3 | 91.0 | 1.134 | 0 | 0 |

| STATION | DATE | TIME | LATITUDE | LONGITUDE | D |
|---|---|---|---|---|---|
| H 184 | JAN 9, 1964 | 1220-1306 | 07° 44.8'S | 096° 52.9'W | 15 |

OBSERVED AND COMPUTED VALUES AT OBSERVED DEPTHS

| Z | T | Cl | S | $O_2$ | $\sigma_T$ | $\delta_T$ | AOU | $PO_4$ | $NO_3$ | $SiO_4$ | $NO_2$ |
|---|---|---|---|---|---|---|---|---|---|---|---|
| (m) | (°C) | (‰) | (‰) | (ml/L) | (gm/L) | (cl/L) | (ml/L) | (µg at./L) | | | |
| 0 | 23.70 | 19.50 | 35.23 | 4.90 | 23.92 | 399.3 | -.19 | -0 | -0 | -0 | -0 |
| 50 | 23.27 | 19.59 | 35.39 | 4.84 | 24.17 | 375.6 | -.11 | -0 | -0 | -0 | -0 |
| 75 | 21.80 | 19.58 | 35.37 | 3.97 | 24.58 | 337.1 | .88 | -0 | -0 | -0 | -0 |
| 100 | 14.78 | 19.34 | 34.94 | .77 | 25.99 | 202.4 | 4.76 | -0 | -0 | -0 | -0 |
| 150 | 12.79 | 19.32 | 34.90 | .27 | 26.38 | 165.7 | 5.50 | -0 | -0 | -0 | -0 |
| 214 | 12.00 | 19.27 | 34.81 | .55 | 26.46 | 157.7 | 5.32 | -0 | -0 | -0 | -0 |
| 313 | 10.94 | 19.26 | 34.79 | .18 | 26.65 | 140.3 | 5.82 | -0 | -0 | -0 | -0 |
| 404 | 9.70 | 19.19 | 34.67 | .16 | 26.76 | 129.1 | 6.02 | -0 | -0 | -0 | -0 |
| 576 | 6.88 | 19.15 | 34.60 | .48 | 27.14 | 93.6 | 6.12 | -0 | -0 | -0 | -0 |

INTERPOLATED AND COMPUTED VALUES AT STANDARD DEPTHS

| Z | T | Cl | S | $\sigma_T$ | $\delta_T$ | $\delta$ | $\Delta D_{Z/0}$ | $\Delta D_{Z/Z\,MAX}$ | $Q_Z$ |
|---|---|---|---|---|---|---|---|---|---|
| (m) | (°C) | (‰) | (‰) | (gm/L) | (cl/T) | (cl/T) | (dyn m) | (dyn m) | (m-dyn m) |
| 0 | 23.70 | 19.50 | 35.23 | 23.92 | 399.3 | 399.5 | 0 | 1.067 | 249.0 |
| 10 | 23.65 | 19.51 | 35.25 | 23.95 | 396.7 | 397.2 | .040 | 1.027 | 238.5 |
| 20 | 23.59 | 19.52 | 35.27 | 23.98 | 393.4 | 394.3 | .079 | .987 | 228.4 |
| 30 | 23.52 | 19.54 | 35.30 | 24.03 | 389.2 | 390.5 | .119 | .948 | 218.8 |
| 50 | 23.27 | 19.59 | 35.39 | 24.17 | 375.6 | 377.7 | .195 | .871 | 200.6 |
| 75 | 21.80 | 19.58 | 35.37 | 24.57 | 337.1 | 340.0 | .285 | .782 | 179.9 |
| 100 | 14.78 | 19.34 | 34.94 | 25.99 | 202.4 | 205.5 | .353 | .714 | 161.2 |
| 150 | 12.79 | 19.32 | 34.90 | 26.38 | 165.7 | 169.8 | .447 | .620 | 127.9 |
| 200 | 12.15 | 19.28 | 34.83 | 26.44 | 159.2 | 164.4 | .531 | .536 | 99.0 |
| 250 | 11.57 | 19.26 | 34.80 | 26.54 | 150.6 | 156.8 | .611 | .456 | 74.2 |
| 300 | 11.06 | 19.26 | 34.80 | 26.62 | 142.3 | 149.5 | .688 | .379 | 53.3 |
| 400 | 9.75 | 19.19 | 34.67 | 26.76 | 129.6 | 138.2 | .831 | .235 | 22.6 |
| 500 | 8.01 | 19.16 | 34.61 | 26.99 | 107.8 | 116.9 | .959 | .108 | 5.4 |
| 600 | 6.56 | 19.15 | 34.59 | 27.18 | 89.5 | 98.8 | 1.067 | 0 | 0 |

| STATION | DATE | TIME | LATITUDE | LONGITUDE | D |
|---|---|---|---|---|---|
| H 189 | JAN 10, 1964 | 1220-1310 | 09° 56.8'S | 099° 46.7'W | 25 |

OBSERVED AND COMPUTED VALUES AT OBSERVED DEPTHS

| Z (m) | T (°C) | Cl (‰) | S (‰) | $O_2$ (ml/L) | $\sigma_T$ (gm/L) | $\delta_T$ (cl/L) | AOU (ml/L) | $PO_4$ (μg at./L) | $NO_3$ (μg at./L) | $SiO_4$ (μg at./L) | $NO_2$ (μg at./L) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 0 | 23.20 | 19.70 | 35.59 | 4.97 | 24.34 | 359.4 | -.24 | -0 | -0 | -0 | -0 |
| 50 | 22.78 | 19.66 | 35.52 | 4.91 | 24.41 | 353.0 | -.14 | -0 | -0 | -0 | -0 |
| 75 | 22.18 | 19.68 | 35.55 | 4.76 | 24.61 | 334.2 | .06 | -0 | -0 | -0 | -0 |
| 100 | 20.23 | 19.63 | 35.46 | 4.56 | 25.07 | 289.8 | .42 | -0 | -0 | -0 | -0 |
| 150 | 16.67 | 19.42 | 35.08 | 3.50 | 25.67 | 232.5 | 1.83 | -0 | -0 | -0 | -0 |
| 188 | 12.45 | 19.25 | 34.78 | .43 | 26.35 | 168.6 | 5.38 | -0 | -0 | -0 | -0 |
| 286 | 10.60 | 19.23 | 34.74 | .56 | 26.66 | 138.5 | 5.49 | -0 | -0 | -0 | -0 |
| 383 | 9.57 | 19.20 | 34.69 | .51 | 26.80 | 125.7 | 5.68 | -0 | -0 | -0 | -0 |
| 566 | 7.19 | 19.15 | 34.60 | .95 | 27.09 | 97.7 | 5.60 | -0 | -0 | -0 | -0 |

INTERPOLATED AND COMPUTED VALUES AT STANDARD DEPTHS

| Z (m) | T (°C) | Cl (‰) | S (‰) | $\sigma_T$ (gm/L) | $\delta_T$ (cl/T) | $\delta$ (cl/T) | $\Delta D_{Z/0}$ (dyn m) | $\Delta D_{Z/Z MAX}$ (dyn m) | $Q_Z$ (m-dynm) |
|---|---|---|---|---|---|---|---|---|---|
| 0 | 23.20 | 19.70 | 35.59 | 24.34 | 359.4 | 359.5 | 0 | 1.104 | 253.5 |
| 10 | 23.15 | 19.70 | 35.58 | 24.35 | 358.7 | 359.2 | .036 | 1.068 | 242.6 |
| 20 | 23.10 | 19.69 | 35.57 | 24.36 | 357.8 | 358.7 | .072 | 1.032 | 232.1 |
| 30 | 23.02 | 19.68 | 35.56 | 24.37 | 356.7 | 357.9 | .108 | .996 | 222.0 |
| 50 | 22.78 | 19.66 | 35.52 | 24.41 | 353.0 | 355.1 | .179 | .925 | 202.8 |
| 75 | 22.18 | 19.68 | 35.55 | 24.60 | 334.2 | 337.1 | .265 | .838 | 180.7 |
| 100 | 20.23 | 19.63 | 35.46 | 25.07 | 289.8 | 293.5 | .344 | .760 | 160.8 |
| 150 | 16.67 | 19.42 | 35.08 | 25.67 | 232.5 | 237.4 | .477 | .627 | 126.1 |
| 200 | 12.18 | 19.25 | 34.77 | 26.39 | 164.2 | 169.4 | .579 | .525 | 97.3 |
| 250 | 11.19 | 19.23 | 34.75 | 26.56 | 148.2 | 154.3 | .660 | .444 | 73.1 |
| 300 | 10.43 | 19.22 | 34.73 | 26.68 | 136.4 | 143.3 | .734 | .370 | 52.7 |
| 400 | 9.31 | 19.19 | 34.67 | 26.83 | 122.6 | 131.0 | .871 | .233 | 22.6 |
| 500 | 7.95 | 19.16 | 34.62 | 27.00 | 106.6 | 115.7 | .995 | .109 | 5.5 |
| 600 | 6.83 | 19.15 | 34.59 | 27.14 | 93.5 | 103.1 | 1.104 | 0 | 0 |

H 189

| STATION | DATE | TIME | LATITUDE | LONGITUDE | D |
|---|---|---|---|---|---|
| H 190 | JAN 11, 1964 | 0620-0700 | 09° 31.9'S | 100° 12.4'W | 20 |

OBSERVED AND COMPUTED VALUES AT OBSERVED DEPTHS

| Z (m) | T (°C) | Cl (‰) | S (‰) | $O_2$ (ml/L) | $\sigma_T$ (gm/L) | $\delta_T$ (cl/L) | AOU (ml/L) | $PO_4$ (μg at./L) | $NO_3$ (μg at./L) | $SiO_4$ (μg at./L) | $NO_2$ (μg at./L) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 0 | 23.00 | 19.72 | 35.62 | 4.91 | 24.43 | 351.3 | -.16 | -0 | -0 | -0 | -0 |
| 50 | 22.87 | 19.71 | 35.61 | 4.95 | 24.45 | 349.0 | -.19 | -0 | -0 | -0 | -0 |
| 75 | 22.73 | 19.72 | 35.62 | 4.78 | 24.50 | 343.9 | -.01 | -0 | -0 | -0 | -0 |
| 100 | 20.21 | 19.67 | 35.53 | 4.34 | 25.13 | 284.1 | .64 | -0 | -0 | -0 | -0 |
| 150 | 14.75 | 19.33 | 34.92 | 2.10 | 25.98 | 203.1 | 3.44 | -0 | -0 | -0 | -0 |
| 199 | 11.98 | 19.27 | 34.81 | .45 | 26.47 | 157.3 | 5.42 | -0 | -0 | -0 | -0 |
| 296 | 10.82 | 19.25 | 34.78 | .62 | 26.65 | 139.6 | 5.40 | -0 | -0 | -0 | -0 |
| 388 | 9.74 | 19.24 | 34.76 | .53 | 26.83 | 123.1 | 5.64 | -0 | -0 | -0 | -0 |
| 578 | 7.30 | 19.17 | 34.63 | .60 | 27.11 | 96.5 | 5.93 | -0 | -0 | -0 | -0 |

H 190

INTERPOLATED AND COMPUTED VALUES AT STANDARD DEPTHS

| Z (m) | T (°C) | Cl (‰) | S (‰) | $\sigma_T$ (gm/L) | $\delta_T$ (cl/T) | $\delta$ (cl/T) | $\Delta D_{Z/0}$ (dyn m) | $\Delta D_{Z/Z MAX}$ (dyn m) | $Q_Z$ (m-dynm) |
|---|---|---|---|---|---|---|---|---|---|
| 0 | 23.00 | 19.72 | 35.62 | 24.43 | 351.3 | 351.4 | 0 | 1.082 | 250.4 |
| 10 | 22.99 | 19.72 | 35.62 | 24.43 | 351.0 | 351.5 | .035 | 1.047 | 239.8 |
| 20 | 22.97 | 19.72 | 35.62 | 24.43 | 350.7 | 351.6 | .070 | 1.012 | 229.5 |
| 30 | 22.94 | 19.72 | 35.62 | 24.44 | 350.3 | 351.5 | .105 | .977 | 219.5 |
| 50 | 22.87 | 19.71 | 35.61 | 24.45 | 349.0 | 351.0 | .176 | .906 | 200.7 |
| 75 | 22.73 | 19.72 | 35.62 | 24.50 | 343.9 | 346.8 | .263 | .819 | 179.1 |
| 100 | 20.21 | 19.67 | 35.53 | 25.13 | 284.1 | 287.8 | .342 | .740 | 159.7 |
| 150 | 14.75 | 19.33 | 34.92 | 25.98 | 203.1 | 207.6 | .466 | .616 | 125.8 |
| 200 | 11.97 | 19.27 | 34.81 | 26.47 | 157.1 | 162.3 | .559 | .524 | 97.3 |
| 250 | 11.31 | 19.26 | 34.79 | 26.57 | 147.1 | 153.3 | .637 | .445 | 73.1 |
| 300 | 10.77 | 19.25 | 34.77 | 26.66 | 138.8 | 145.8 | .712 | .370 | 52.7 |
| 400 | 9.55 | 19.23 | 34.75 | 26.85 | 121.1 | 129.6 | .850 | .232 | 22.6 |
| 500 | 8.19 | 19.19 | 34.67 | 27.00 | 106.2 | 115.5 | .973 | .110 | 5.5 |
| 600 | 7.07 | 19.17 | 34.62 | 27.13 | 94.0 | 103.9 | 1.082 | 0 | 0 |

| STATION | DATE | TIME | LATITUDE | LONGITUDE | D |
|---|---|---|---|---|---|
| H 195 | JAN 12,1964 | 0800-0843 | 6° 48.0'S | 100° 24.9'W | 21 |

OBSERVED AND COMPUTED VALUES AT OBSERVED DEPTHS

| Z (m) | T (°C) | Cl (‰) | S (‰) | $O_2$ (ml/L) | $\sigma_T$ (gm/L) | $\delta_T$ (cl/L) | AOU (ml/L) | $PO_4$ | $NO_3$ | $SiO_4$ | $NO_2$ |
|---|---|---|---|---|---|---|---|---|---|---|---|
|  |  |  |  |  |  |  |  | —— (µg at./L) —— |  |  |  |
| 0 | 24.10 | 999.00 | 999.00 | 4.83 | 999.00 | 999.0 | 999.00 | -0 | -0 | -0 | -0 |
| 49 | 23.87 | 999.00 | 999.00 | 4.82 | 999.00 | 999.0 | 999.00 | -0 | -0 | -0 | -0 |
| 73 | 23.65 | 999.00 | 999.00 | 4.74 | 999.00 | 999.0 | 999.00 | -0 | -0 | -0 | -0 |
| 97 | 19.69 | 999.00 | 999.00 | 3.84 | 999.00 | 999.0 | 999.00 | -0 | -0 | -0 | -0 |
| 146 | 13.71 | 999.00 | 999.00 | 2.69 | 999.00 | 999.0 | 999.00 | -0 | -0 | -0 | -0 |
| 219 | 11.73 | 999.00 | 999.00 | .48 | 999.00 | 999.0 | 999.00 | -0 | -0 | -0 | -0 |
| 319 | 10.71 | 999.00 | 999.00 | .33 | 999.00 | 999.0 | 999.00 | -0 | -0 | -0 | -0 |
| 408 | 9.55 | 999.00 | 999.00 | .28 | 999.00 | 999.0 | 999.00 | -0 | -0 | -0 | -0 |
| 598 | 7.24 | 999.00 | 999.00 | .45 | 999.00 | 999.0 | 999.00 | -0 | -0 | -0 | -0 |

INTERPOLATED AND COMPUTED VALUES AT STANDARD DEPTHS

| Z (m) | T (°C) | Cl (‰) | S (‰) | $\sigma_T$ (gm/L) | $\delta_T$ (cl/T) | $\delta$ (cl/T) | $\Delta D_{Z/0}$ (dyn m) | $\Delta D_{Z/Z\,MAX}$ (dyn m) | $Q_Z$ (m-dynm) |
|---|---|---|---|---|---|---|---|---|---|
| 0 | 24.10 |  |  |  |  |  |  |  |  |
| 10 | 24.07 |  |  |  |  |  |  |  |  |
| 20 | 24.04 |  |  |  |  |  |  |  |  |
| 30 | 24.00 |  |  |  |  |  |  |  |  |
| 50 | 23.86 |  |  |  |  |  |  |  |  |
| 75 | 23.44 |  |  |  |  |  |  |  |  |
| 100 | 19.25 |  |  |  |  |  |  |  |  |
| 150 | 13.58 |  |  |  |  |  |  |  |  |
| 200 | 12.17 |  |  |  |  |  |  |  |  |
| 250 | 11.37 |  |  |  |  |  |  |  |  |
| 300 | 10.88 |  |  |  |  |  |  |  |  |
| 400 | 9.64 |  |  |  |  |  |  |  |  |
| 500 | 8.32 |  |  |  |  |  |  |  |  |
| 600 | 7.22 |  |  |  |  |  |  |  |  |

| STATION | DATE | TIME | LATITUDE | LONGITUDE | D |
|---|---|---|---|---|---|
| H 198 | JAN 13, 1964 | 0630-0700 | 05° 10.4'S | 100° 49.8'W | 15 |

OBSERVED AND COMPUTED VALUES AT OBSERVED DEPTHS

| Z (m) | T (°C) | Cl (‰) | S (‰) | $O_2$ (ml/L) | $\sigma_T$ (gm/L) | $\delta_T$ (cl/L) | AOU (ml/L) | $PO_4$ | $NO_3$ | $SiO_4$ | $NO_2$ |
|---|---|---|---|---|---|---|---|---|---|---|---|
|  |  |  |  |  |  |  |  | —— (µg at./L) —— |  |  |  |
| 0 | 24.20 | 19.31 | 34.88 | 4.81 | 23.52 | 438.2 | -.13 | -0 | -0 | -0 | -0 |
| 50 | 24.17 | 19.30 | 34.87 | 4.83 | 23.51 | 438.6 | -.15 | -0 | -0 | -0 | -0 |
| 75 | 19.28 | 19.45 | 35.14 | 2.96 | 25.07 | 289.7 | 2.12 | -0 | -0 | -0 | -0 |
| 100 | 15.82 | 19.43 | 35.10 | 1.51 | 25.88 | 212.6 | 3.91 | -0 | -0 | -0 | -0 |
| 150 | 13.50 | 19.36 | 34.97 | 1.56 | 26.29 | 174.0 | 4.12 | -0 | -0 | -0 | -0 |
| 200 | 12.93 | 19.34 | 34.94 | 1.57 | 26.38 | 165.7 | 4.18 | -0 | -0 | -0 | -0 |
| 296 | 12.12 | 19.30 | 34.87 | .33 | 26.48 | 155.9 | 5.52 | -0 | -0 | -0 | -0 |
| 392 | 10.84 | 19.28 | 34.83 | .22 | 26.69 | 135.9 | 5.80 | -0 | -0 | -0 | -0 |
| 573 | 7.52 | 19.17 | 34.63 | .30 | 27.08 | 99.5 | 6.20 | -0 | -0 | -0 | -0 |

INTERPOLATED AND COMPUTED VALUES AT STANDARD DEPTHS

| Z (m) | T (°C) | Cl (‰) | S (‰) | $\sigma_T$ (gm/L) | $\delta_T$ (cl/T) | $\delta$ (cl/T) | $\Delta D_{Z/0}$ (dyn m) | $\Delta D_{Z/Z\,MAX}$ (dyn m) | $Q_Z$ (m-dynm) |
|---|---|---|---|---|---|---|---|---|---|
| 0 | 24.20 | 19.31 | 34.88 | 23.51 | 438.2 | 438.3 | 0 | 1.127 | 261.9 |
| 10 | 24.20 | 19.31 | 34.88 | 23.51 | 438.4 | 439.0 | .044 | 1.083 | 250.8 |
| 20 | 24.19 | 19.31 | 34.88 | 23.51 | 438.5 | 439.4 | .088 | 1.039 | 240.2 |
| 30 | 24.19 | 19.30 | 34.87 | 23.51 | 438.6 | 439.8 | .132 | .995 | 230.0 |
| 50 | 24.17 | 19.30 | 34.87 | 23.51 | 438.6 | 440.7 | .220 | .907 | 211.0 |
| 75 | 19.28 | 19.45 | 35.14 | 25.07 | 289.7 | 292.5 | .311 | .816 | 189.5 |
| 100 | 15.82 | 19.43 | 35.10 | 25.88 | 212.6 | 215.7 | .375 | .752 | 169.9 |
| 150 | 13.50 | 19.36 | 34.97 | 26.29 | 174.0 | 178.3 | .473 | .654 | 134.7 |
| 200 | 12.93 | 19.34 | 34.94 | 26.38 | 165.7 | 171.1 | .561 | .566 | 104.2 |
| 250 | 12.47 | 19.32 | 34.90 | 26.44 | 160.1 | 166.7 | .645 | .482 | 78.0 |
| 300 | 12.06 | 19.30 | 34.86 | 26.49 | 154.9 | 162.6 | .728 | .399 | 56.0 |
| 400 | 10.66 | 19.27 | 34.82 | 26.71 | 134.0 | 143.3 | .881 | .247 | 23.7 |
| 500 | 8.71 | 19.20 | 34.69 | 26.94 | 112.6 | 122.4 | 1.013 | .114 | 5.7 |
| 600 | 7.12 | 19.16 | 34.62 | 27.12 | 95.1 | 105.0 | 1.127 | 0 | 0 |

| STATION | DATE | TIME | LATITUDE | LONGITUDE | D |
|---|---|---|---|---|---|
| H 202 | JAN 14, 1964 | 0803-0850 | 02° 37.5'S | 101° 06.2'W | 21 |

OBSERVED AND COMPUTED VALUES AT OBSERVED DEPTHS

| Z (m) | T (°C) | Cl (‰) | S (‰) | $O_2$ (ml/L) | $\sigma_T$ (gm/L) | $\delta_T$ (cl/L) | AOU (ml/L) | $PO_4$ (μg at./L) | $NO_3$ (μg at./L) | $SiO_4$ (μg at./L) | $NO_2$ (μg at./L) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 0 | 24.30 | 19.18 | 34.65 | 4.53 | 23.31 | 457.9 | .15 | -0 | -0 | -0 | -0 |
| 42 | 23.79 | 19.19 | 34.67 | 4.46 | 23.47 | 442.2 | .26 | -0 | -0 | -0 | -0 |
| 64 | 23.29 | 19.33 | 34.92 | 4.17 | 23.81 | 410.1 | .58 | -0 | -0 | -0 | -0 |
| 85 | 16.25 | 19.42 | 35.08 | 1.81 | 25.77 | 223.2 | 3.56 | -0 | -0 | -0 | -0 |
| 127 | 13.48 | 19.36 | 34.97 | 1.88 | 26.29 | 173.7 | 3.80 | -0 | -0 | -0 | -0 |
| 249 | 12.56 | 19.31 | 34.88 | 1.20 | 26.41 | 162.7 | 4.59 | -0 | -0 | -0 | -0 |
| 338 | 11.49 | 19.28 | 34.83 | .23 | 26.57 | 147.2 | 5.70 | -0 | -0 | -0 | -0 |
| 421 | 9.19 | 19.23 | 34.74 | .77 | 26.90 | 115.8 | 5.48 | -0 | -0 | -0 | -0 |
| 595 | 6.99 | 19.18 | 34.65 | 1.06 | 27.17 | 91.0 | 5.52 | -0 | -0 | -0 | -0 |

INTERPOLATED AND COMPUTED VALUES AT STANDARD DEPTHS

| Z (m) | T (°C) | Cl (‰) | S (‰) | $\sigma_T$ (gm/L) | $\delta_T$ (cl/T) | $\delta$ (cl/T) | $\Delta D_{Z/0}$ (dyn m) | $\Delta D_{Z/Z MAX}$ (dyn m) | $Q_Z$ (m-dynm) |
|---|---|---|---|---|---|---|---|---|---|
| 0 | 24.30 | 19.18 | 34.65 | 23.31 | 457.9 | 458.0 | 0 | 1.109 | 250.9 |
| 10 | 24.23 | 19.18 | 34.65 | 23.33 | 455.8 | 456.3 | .046 | 1.063 | 240.0 |
| 20 | 24.14 | 19.18 | 34.65 | 23.36 | 453.0 | 453.9 | .091 | 1.017 | 229.6 |
| 30 | 24.02 | 19.19 | 34.66 | 23.40 | 449.2 | 450.5 | .136 | .972 | 219.6 |
| 50 | 23.64 | 19.23 | 34.73 | 23.56 | 433.4 | 435.4 | .225 | .884 | 201.1 |
| 75 | 19.59 | 19.34 | 34.94 | 24.84 | 311.9 | 314.7 | .319 | .790 | 180.2 |
| 100 | 15.13 | 19.39 | 35.03 | 25.98 | 203.2 | 206.3 | .384 | .725 | 161.2 |
| 150 | 13.25 | 19.35 | 34.95 | 26.32 | 171.0 | 175.1 | .479 | .629 | 127.4 |
| 200 | 12.86 | 19.33 | 34.91 | 26.37 | 166.3 | 171.7 | .566 | .543 | 98.1 |
| 250 | 12.55 | 19.31 | 34.88 | 26.41 | 162.5 | 169.1 | .651 | .457 | 73.1 |
| 300 | 11.91 | 19.29 | 34.85 | 26.51 | 153.3 | 160.9 | .734 | .375 | 52.3 |
| 400 | 9.73 | 19.24 | 34.75 | 26.83 | 123.1 | 131.8 | .880 | .229 | 22.1 |
| 500 | 8.10 | 19.20 | 34.69 | 27.03 | 103.5 | 112.7 | 1.002 | .106 | 5.3 |
| 600 | 6.94 | 19.18 | 34.65 | 27.17 | 90.4 | 100.1 | 1.109 | 0 | 0 |

H 202

| STATION | DATE | TIME | LATITUDE | LONGITUDE | D |
|---|---|---|---|---|---|
| H 205 | JAN 15, 1964 | 0559-0715 | 00° 50.4'S | 101° 40.5'W | |

OBSERVED AND COMPUTED VALUES AT OBSERVED DEPTHS

| Z (m) | T (°C) | Cl (‰) | S (‰) | $O_2$ (ml/L) | $\sigma_T$ (gm/L) | $\delta_T$ (cl/L) | AOU (ml/L) | $PO_4$ (μg at./L) | $NO_3$ (μg at./L) | $SiO_4$ (μg at./L) | $NO_2$ (μg at./L) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 0 | 24.60 | 19.10 | 34.51 | 4.69 | 23.11 | 476.9 | -.03 | -0 | -0 | -0 | -0 |
| 49 | 20.39 | 19.27 | 34.81 | 3.37 | 24.53 | 341.0 | 1.62 | -0 | -0 | -0 | -0 |
| 73 | 18.12 | 19.55 | 35.32 | 2.18 | 25.50 | 248.7 | 3.00 | -0 | -0 | -0 | -0 |
| 97 | 14.41 | 19.42 | 35.08 | 1.97 | 26.18 | 184.3 | 3.60 | -0 | -0 | -0 | -0 |
| 146 | 12.98 | 19.39 | 35.03 | 2.18 | 26.44 | 160.0 | 3.56 | -0 | -0 | -0 | -0 |
| 209 | 12.68 | 19.33 | 34.92 | 1.80 | 26.41 | 162.3 | 3.98 | -0 | -0 | -0 | -0 |
| 308 | 11.58 | 19.29 | 34.85 | .27 | 26.57 | 147.5 | 5.65 | -0 | -0 | -0 | -0 |
| 405 | 8.99 | 19.21 | 34.70 | .59 | 26.91 | 115.4 | 5.69 | -0 | -0 | -0 | -0 |
| 586 | 6.64 | 19.16 | 34.61 | 1.50 | 27.18 | 89.2 | 5.14 | -0 | -0 | -0 | -0 |

H 205

INTERPOLATED AND COMPUTED VALUES AT STANDARD DEPTHS

| Z (m) | T (°C) | Cl (‰) | S (‰) | $\sigma_T$ (gm/L) | $\delta_T$ (cl/T) | $\delta$ (cl/T) | $\Delta D_{Z/0}$ (dyn m) | $\Delta D_{Z/Z MAX}$ (dyn m) | $Q_Z$ (m-dynm) |
|---|---|---|---|---|---|---|---|---|---|
| 0 | 24.60 | 19.10 | 34.51 | 23.11 | 476.9 | 477.0 | 0 | 1.031 | 238.7 |
| 10 | 24.12 | 19.11 | 34.53 | 23.27 | 461.5 | 462.0 | .047 | .984 | 228.6 |
| 20 | 23.52 | 19.13 | 34.57 | 23.47 | 442.1 | 442.9 | .092 | .939 | 219.0 |
| 30 | 22.74 | 19.16 | 34.62 | 23.74 | 416.9 | 418.2 | .135 | .896 | 209.8 |
| 50 | 20.31 | 19.28 | 34.83 | 24.57 | 337.9 | 339.8 | .211 | .820 | 192.7 |
| 75 | 17.84 | 19.54 | 35.30 | 25.56 | 243.7 | 246.3 | .284 | .747 | 173.1 |
| 100 | 14.30 | 19.42 | 35.08 | 26.20 | 182.5 | 185.5 | .338 | .693 | 155.1 |
| 150 | 12.96 | 19.39 | 35.02 | 26.43 | 160.7 | 164.3 | .426 | .605 | 122.6 |
| 200 | 12.72 | 19.34 | 34.93 | 26.42 | 162.0 | 167.4 | .509 | .522 | 94.4 |
| 250 | 12.17 | 19.31 | 34.88 | 26.48 | 155.5 | 161.9 | .591 | .440 | 70.4 |
| 300 | 11.65 | 19.29 | 34.85 | 26.56 | 148.5 | 156.0 | .670 | .361 | 50.3 |
| 400 | 9.11 | 19.21 | 34.71 | 26.89 | 116.9 | 125.1 | .811 | .220 | 21.3 |
| 500 | 7.65 | 19.18 | 34.64 | 27.06 | 100.4 | 109.3 | .928 | .103 | 5.1 |
| 600 | 6.49 | 19.16 | 34.61 | 27.20 | 87.5 | 96.6 | 1.031 | 0 | 0 |

| STATION | DATE | TIME | LATITUDE | LONGITUDE | D |
|---|---|---|---|---|---|
| H 209 | JAN 16, 1964 | 0800-0900 | 01° 47.9'N | 101° 48.3'W | 21 |

OBSERVED AND COMPUTED VALUES AT OBSERVED DEPTHS

| Z (m) | T (°C) | Cl (‰) | S (‰) | $O_2$ (ml/L) | $\sigma_T$ (gm/L) | $\delta_T$ (cl/L) | AOU (ml/L) | $PO_4$ | $NO_3$ | $SiO_4$ | $NO_2$ |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | — (µg at./L) — | | | |
| 0 | 25.00 | 19.05 | 34.42 | 4.64 | 22.92 | 494.9 | -.01 | -0 | -0 | -0 | -0 |
| 50 | 19.40 | 19.27 | 34.81 | 3.24 | 24.79 | 316.3 | 1.84 | -0 | -0 | -0 | -0 |
| 75 | 15.25 | 19.28 | 34.83 | 1.74 | 25.80 | 220.2 | 3.75 | -0 | -0 | -0 | -0 |
| 100 | 14.39 | 19.34 | 34.94 | 1.77 | 26.08 | 194.4 | 3.81 | -0 | -0 | -0 | -0 |
| 150 | 13.44 | 19.34 | 34.94 | 1.71 | 26.27 | 175.5 | 3.98 | -0 | -0 | -0 | -0 |
| 218 | 12.82 | 19.33 | 34.92 | 1.60 | 26.39 | 164.9 | 4.16 | -0 | -0 | -0 | -0 |
| 317 | 12.01 | 19.30 | 34.87 | .77 | 26.50 | 153.9 | 5.09 | -0 | -0 | -0 | -0 |
| 406 | 8.80 | 19.19 | 34.67 | .41 | 26.91 | 115.2 | 5.90 | -0 | -0 | -0 | -0 |
| 600 | 6.64 | 19.17 | 34.63 | 1.22 | 27.20 | 87.8 | 5.42 | -0 | -0 | -0 | -0 |

INTERPOLATED AND COMPUTED VALUES AT STANDARD DEPTHS

| Z (m) | T (°C) | Cl (‰) | S (‰) | $\sigma_T$ (gm/L) | $\delta_T$ (cl/T) | $\delta$ (cl/T) | $\Delta D_{Z/0}$ (dyn m) | $\Delta D_{Z/Z\,MAX}$ (dyn m) | $Q_Z$ (m-dyn m) |
|---|---|---|---|---|---|---|---|---|---|
| 0 | 25.00 | 19.05 | 34.41 | 22.92 | 494.9 | 495.1 | 0 | 1.048 | 243.2 |
| 10 | 24.38 | 19.07 | 34.44 | 23.13 | 475.1 | 475.6 | .049 | .999 | 232.9 |
| 20 | 23.60 | 19.09 | 34.48 | 23.39 | 450.3 | 451.2 | .095 | .953 | 223.2 |
| 30 | 22.60 | 19.12 | 34.54 | 23.72 | 418.4 | 419.6 | .138 | .909 | 213.8 |
| 50 | 19.40 | 19.27 | 34.81 | 24.79 | 316.3 | 318.1 | .212 | .836 | 196.4 |
| 75 | 15.25 | 19.28 | 34.83 | 25.80 | 220.2 | 222.5 | .280 | .768 | 176.4 |
| 100 | 14.39 | 19.34 | 34.94 | 26.07 | 194.4 | 197.4 | .332 | .715 | 157.8 |
| 150 | 13.44 | 19.34 | 34.94 | 26.27 | 175.5 | 179.8 | .427 | .621 | 124.4 |
| 200 | 12.96 | 19.33 | 34.92 | 26.36 | 167.4 | 172.8 | .515 | .533 | 95.5 |
| 250 | 12.52 | 19.32 | 34.90 | 26.43 | 160.9 | 167.5 | .600 | .448 | 71.0 |
| 300 | 12.13 | 19.30 | 34.87 | 26.48 | 155.5 | 163.2 | .682 | .365 | 50.7 |
| 400 | 8.99 | 19.19 | 34.68 | 26.88 | 117.5 | 125.6 | .827 | .221 | 21.4 |
| 500 | 7.65 | 19.17 | 34.64 | 27.06 | 100.6 | 109.4 | .944 | .103 | 5.2 |
| 600 | 6.64 | 19.17 | 34.63 | 27.20 | 87.8 | 97.2 | 1.048 | 0 | 0 |

| STATION | DATE | TIME | LATITUDE | LONGITUDE | D |
|---|---|---|---|---|---|
| H 212 | JAN 17, 1964 | 0625- | 03° 26.0'N | 101° 49.2'W | 20 |

OBSERVED AND COMPUTED VALUES AT OBSERVED DEPTHS

| Z (m) | T (°C) | Cl (‰) | S (‰) | $O_2$ (ml/L) | $\sigma_T$ (gm/L) | $\delta_T$ (cl/L) | AOU (ml/L) | $PO_4$ | $NO_3$ | $SiO_4$ | $NO_2$ |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | — (µg at./L) — | | | |
| 0 | 26.30 | 18.93 | 34.20 | 4.52 | 22.36 | 548.8 | .02 | -0 | -0 | -0 | -0 |
| 50 | 26.04 | 18.94 | 34.22 | 4.61 | 22.45 | 539.8 | -.05 | -0 | -0 | -0 | -0 |
| 74 | 18.98 | 19.27 | 34.81 | 2.81 | 24.90 | 306.0 | 2.31 | -0 | -0 | -0 | -0 |
| 99 | 14.74 | 19.36 | 34.97 | 2.04 | 26.03 | 199.0 | 3.50 | -0 | -0 | -0 | -0 |
| 149 | 13.52 | 19.35 | 34.96 | 1.77 | 26.27 | 175.8 | 3.91 | -0 | -0 | -0 | -0 |
| 222 | 12.86 | 19.31 | 34.88 | 1.32 | 26.35 | 168.3 | 4.44 | -0 | -0 | -0 | -0 |
| 322 | 11.17 | 19.24 | 34.76 | 1.02 | 26.58 | 146.9 | 4.95 | -0 | -0 | -0 | -0 |
| 413 | 9.45 | 19.20 | 34.69 | .62 | 26.82 | 123.9 | 5.59 | -0 | -0 | -0 | -0 |
| 597 | 7.25 | 19.17 | 34.63 | .79 | 27.11 | 95.8 | 5.75 | -0 | -0 | -0 | -0 |

INTERPOLATED AND COMPUTED VALUES AT STANDARD DEPTHS

| Z (m) | T (°C) | Cl (‰) | S (‰) | $\sigma_T$ (gm/L) | $\delta_T$ (cl/T) | $\delta$ (cl/T) | $\Delta D_{Z/0}$ (dyn m) | $\Delta D_{Z/Z\,MAX}$ (dyn m) | $Q_Z$ (m-dynm) |
|---|---|---|---|---|---|---|---|---|---|
| 0 | 26.30 | 18.93 | 34.20 | 22.36 | 548.8 | 548.9 | 0 | 1.180 | 258.5 |
| 10 | 26.27 | 18.93 | 34.20 | 22.37 | 547.8 | 548.3 | .055 | 1.125 | 247.0 |
| 20 | 26.23 | 18.93 | 34.20 | 22.38 | 546.6 | 547.5 | .110 | 1.070 | 236.0 |
| 30 | 26.19 | 18.93 | 34.21 | 22.40 | 545.0 | 546.3 | .164 | 1.016 | 225.6 |
| 50 | 26.04 | 18.94 | 34.22 | 22.45 | 539.8 | 541.9 | .273 | .907 | 206.3 |
| 75 | 18.78 | 19.27 | 34.81 | 24.95 | 301.1 | 303.8 | .379 | .801 | 185.0 |
| 100 | 14.71 | 19.36 | 34.97 | 26.03 | 198.4 | 201.4 | .442 | .738 | 165.7 |
| 150 | 13.51 | 19.35 | 34.96 | 26.27 | 175.6 | 179.9 | .537 | .643 | 131.2 |
| 200 | 13.03 | 19.32 | 34.90 | 26.33 | 170.3 | 175.8 | .626 | .554 | 101.3 |
| 250 | 12.32 | 19.29 | 34.84 | 26.42 | 161.5 | 168.0 | .712 | .468 | 75.8 |
| 300 | 11.49 | 19.25 | 34.78 | 26.53 | 151.0 | 158.4 | .794 | .386 | 54.4 |
| 400 | 9.67 | 19.20 | 34.69 | 26.79 | 126.8 | 135.4 | .941 | .239 | 23.2 |
| 500 | 8.31 | 19.18 | 34.65 | 26.97 | 109.3 | 118.8 | 1.068 | .112 | 5.6 |
| 600 | 7.22 | 19.17 | 34.63 | 27.12 | 95.4 | 105.5 | 1.180 | 0 | 0 |

| STATION | DATE | TIME | LATITUDE | LONGITUDE | D |
|---|---|---|---|---|---|
| h 216 | JAN 18, 1964 | 0800-0852 | 06° 03.2'N | 102° 05.7'W | 25 |

OBSERVED AND COMPUTED VALUES AT OBSERVED DEPTHS

| Z (m) | T (°C) | Cl (‰) | S (‰) | $O_2$ (ml/L) | $\sigma_T$ (gm/L) | $\delta_T$ (cl/L) | AOU (ml/L) | $PO_4$ (µg at./L) | $NO_3$ (µg at./L) | $SiO_4$ (µg at./L) | $NO_2$ (µg at./L) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 0 | 27.20 | 18.84 | 34.04 | 4.40 | 21.95 | 587.8 | .09 | -0 | -0 | -0 | -0 |
| 49 | 26.81 | 19.00 | 34.33 | 4.56 | 22.29 | 555.1 | -.06 | -0 | -0 | -0 | -0 |
| 73 | 21.75 | 19.24 | 34.76 | 3.73 | 24.12 | 380.1 | 1.15 | -0 | -0 | -0 | -0 |
| 97 | 16.03 | 19.25 | 34.78 | 1.87 | 25.59 | 240.8 | 3.54 | -0 | -0 | -0 | -0 |
| 146 | 12.17 | 19.25 | 34.78 | .97 | 26.40 | 163.5 | 4.88 | -0 | -0 | -0 | -0 |
| 226 | 10.71 | 19.23 | 34.74 | .98 | 26.64 | 140.4 | 5.06 | -0 | -0 | -0 | -0 |
| 322 | 9.67 | 19.21 | 34.70 | .95 | 26.80 | 126.0 | 5.23 | -0 | -0 | -0 | -0 |
| 410 | 8.91 | 19.20 | 34.69 | .50 | 26.91 | 115.5 | 5.79 | -0 | -0 | -0 | -0 |
| 585 | 6.77 | 19.15 | 34.60 | .49 | 27.15 | 92.2 | 6.13 | -0 | -0 | -0 | -0 |

H 216

INTERPOLATED AND COMPUTED VALUES AT STANDARD DEPTHS

| Z (m) | T (°C) | Cl (‰) | S (‰) | $\sigma_T$ (gm/L) | $\delta_T$ (cl/T) | $\delta$ (cl/T) | $\Delta D_{Z/0}$ (dyn m) | $\Delta D_{Z/Z\,MAX}$ (dyn m) | $Q_Z$ (m-dynm) |
|---|---|---|---|---|---|---|---|---|---|
| 0 | 27.20 | 18.84 | 34.04 | 21.95 | 587.8 | 587.9 | 0 | 1.156 | 239.9 |
| 10 | 27.16 | 18.86 | 34.07 | 21.99 | 584.1 | 584.6 | .059 | 1.098 | 228.6 |
| 20 | 27.10 | 18.88 | 34.11 | 22.04 | 579.4 | 580.3 | .117 | 1.040 | 217.9 |
| 30 | 27.03 | 18.91 | 34.16 | 22.10 | 573.4 | 574.7 | .175 | .982 | 207.8 |
| 50 | 26.69 | 19.01 | 34.34 | 22.34 | 550.8 | 553.0 | .287 | .869 | 189.3 |
| 75 | 21.34 | 19.24 | 34.75 | 24.23 | 369.8 | 372.6 | .403 | .753 | 169.0 |
| 100 | 15.74 | 19.25 | 34.77 | 25.65 | 235.1 | 238.2 | .479 | .677 | 151.2 |
| 150 | 12.08 | 19.25 | 34.77 | 26.42 | 162.0 | 166.0 | .580 | .576 | 119.8 |
| 200 | 11.12 | 19.23 | 34.75 | 26.58 | 146.9 | 151.7 | .660 | .497 | 93.0 |
| 250 | 10.41 | 19.22 | 34.73 | 26.69 | 136.3 | 142.1 | .733 | .423 | 70.0 |
| 300 | 9.88 | 19.21 | 34.71 | 26.76 | 128.9 | 135.5 | .803 | .354 | 50.6 |
| 400 | 8.99 | 19.20 | 34.69 | 26.89 | 116.6 | 124.7 | .933 | .224 | 21.7 |
| 500 | 7.72 | 19.17 | 34.63 | 27.04 | 102.5 | 111.4 | 1.051 | .106 | 5.3 |
| 600 | 6.62 | 19.15 | 34.59 | 27.17 | 90.5 | 99.8 | 1.156 | 0 | 0 |

| STATION | DATE | TIME | LATITUDE | LONGITUDE | D |
|---|---|---|---|---|---|
| H 219 | JAN 19, 1964 | 0620-0710 | 7° 49.4'N | 102° 45.4'W | 26 |

OBSERVED AND COMPUTED VALUES AT OBSERVED DEPTHS

| Z (m) | T (°C) | Cl (‰) | S (‰) | $O_2$ (ml/L) | $\sigma_T$ (gm/L) | $\delta_T$ (cl/L) | AOU (ml/L) | $PO_4$ (µg at./L) | $NO_3$ (µg at./L) | $SiO_4$ (µg at./L) | $NO_2$ (µg at./L) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 0 | 27.00 | 999.00 | 999.00 | 4.45 | 999.00 | 999.0 | 999.00 | -0 | -0 | -0 | -0 |
| 49 | 21.45 | 999.00 | 999.00 | 3.22 | 999.00 | 999.0 | 999.00 | -0 | -0 | -0 | -0 |
| 73 | 16.81 | 999.00 | 999.00 | 1.51 | 999.00 | 999.0 | 999.00 | -0 | -0 | -0 | -0 |
| 98 | 13.47 | 999.00 | 999.00 | .60 | 999.00 | 999.0 | 999.00 | -0 | -0 | -0 | -0 |
| 147 | 12.57 | 999.00 | 999.00 | .80 | 999.00 | 999.0 | 999.00 | -0 | -0 | -0 | -0 |
| 222 | 11.84 | 999.00 | 999.00 | 1.01 | 999.00 | 999.0 | 999.00 | -0 | -0 | -0 | -0 |
| 297 | 10.52 | 999.00 | 999.00 | .41 | 999.00 | 999.0 | 999.00 | -0 | -0 | -0 | -0 |
| 389 | 9.53 | 999.00 | 999.00 | .18 | 999.00 | 999.0 | 999.00 | -0 | -0 | -0 | -0 |
| 565 | 7.05 | 999.00 | 999.00 | .22 | 999.00 | 999.0 | 999.00 | -0 | -0 | -0 | -0 |

H 219

INTERPOLATED AND COMPUTED VALUES AT STANDARD DEPTHS

| Z (m) | T (°C) | Cl (‰) | S (‰) | $\sigma_T$ (gm/L) | $\delta_T$ (cl/T) | $\delta$ (cl/T) | $\Delta D_{Z/0}$ (dyn m) | $\Delta D_{Z/Z\,MAX}$ (dyn m) | $Q_Z$ (m-dynm) |
|---|---|---|---|---|---|---|---|---|---|
| 0 | 27.00 | | | | | | | | |
| 10 | 26.37 | | | | | | | | |
| 20 | 25.58 | | | | | | | | |
| 30 | 24.55 | | | | | | | | |
| 50 | 21.28 | | | | | | | | |
| 75 | 16.50 | | | | | | | | |
| 100 | 13.43 | | | | | | | | |
| 150 | 12.53 | | | | | | | | |
| 200 | 12.02 | | | | | | | | |
| 250 | 11.30 | | | | | | | | |
| 300 | 10.48 | | | | | | | | |
| 400 | 9.34 | | | | | | | | |
| 500 | 7.86 | | | | | | | | |
| 600 | 6.65 | | | | | | | | |

| STATION | DATE | TIME | LATITUDE | LONGITUDE | D |
|---|---|---|---|---|---|
| H 223 | JAN 20, 1963 | 0803- | 10° 32.3'N | 102° 47.6'W | 27 |

OBSERVED AND COMPUTED VALUES AT OBSERVED DEPTHS

| Z | T | Cl | S | $O_2$ | $\sigma_T$ | $\delta_T$ | AOU | $PO_4$ | $NO_3$ | $SiO_4$ | $NO_2$ |
|---|---|---|---|---|---|---|---|---|---|---|---|
| (m) | (°C) | (‰) | (‰) | (ml/L) | (gm/L) | (cl/L) | (ml/L) | (µg at./L) | | | |
| 0 | 27.40 | 999.00 | 999.00 | 4.47 | 999.00 | 999.0 | 999.00 | -0 | -0 | -0 | -0 |
| 45 | 26.74 | 999.00 | 999.00 | 4.52 | 999.00 | 999.0 | 999.00 | -0 | -0 | -0 | -0 |
| 68 | 20.69 | 999.00 | 999.00 | 2.63 | 999.00 | 999.0 | 999.00 | -0 | -0 | -0 | -0 |
| 91 | 13.93 | 999.00 | 999.00 | .28 | 999.00 | 999.0 | 999.00 | -0 | -0 | -0 | -0 |
| 137 | 12.48 | 999.00 | 999.00 | .60 | 999.00 | 999.0 | 999.00 | -0 | -0 | -0 | -0 |
| 216 | 11.22 | 999.00 | 999.00 | .58 | 999.00 | 999.0 | 999.00 | -0 | -0 | -0 | -0 |
| 307 | 10.39 | 999.00 | 999.00 | .48 | 999.00 | 999.0 | 999.00 | -0 | -0 | -0 | -0 |
| 386 | 9.54 | 999.00 | 999.00 | .22 | 999.00 | 999.0 | 999.00 | -0 | -0 | -0 | -0 |
| 556 | 7.31 | 999.00 | 999.00 | .33 | 999.00 | 999.0 | 999.00 | -0 | -0 | -0 | -0 |

INTERPOLATED AND COMPUTED VALUES AT STANDARD DEPTHS

| Z | T | Cl | S | $\sigma_T$ | $\delta_T$ | $\delta$ | $\Delta D_{Z/0}$ | $\Delta D_{Z/Z\,MAX}$ | $Q_Z$ |
|---|---|---|---|---|---|---|---|---|---|
| (m) | (°C) | (‰) | (‰) | (gm/L) | (cl/T) | (cl/T) | (dyn m) | (dyn m) | (m-dynm) |
| 0 | 27.40 | | | | | | | | |
| 10 | 27.32 | | | | | | | | |
| 20 | 27.21 | | | | | | | | |
| 30 | 27.07 | | | | | | | | |
| 50 | 25.94 | | | | | | | | |
| 75 | 18.78 | | | | | | | | |
| 100 | 13.60 | | | | | | | | |
| 150 | 12.23 | | | | | | | | |
| 200 | 11.43 | | | | | | | | |
| 250 | 10.88 | | | | | | | | |
| 300 | 10.44 | | | | | | | | |
| 400 | 9.32 | | | | | | | | |
| 500 | 7.96 | | | | | | | | |
| 600 | 6.84 | | | | | | | | |

| STATION | DATE | TIME | LATITUDE | LONGITUDE | D |
|---|---|---|---|---|---|
| H 226 | JAN 21, 1964 | 0618-0713 | 12° 40.0'N | 103° 27.8'W | 26 |

OBSERVED AND COMPUTED VALUES AT OBSERVED DEPTHS

| Z | T | Cl | S | $O_2$ | $\sigma_T$ | $\delta_T$ | AOU | $PO_4$ | $NO_3$ | $SiO_4$ | $NO_2$ |
|---|---|---|---|---|---|---|---|---|---|---|---|
| (m) | (°C) | (‰) | (‰) | (ml/L) | (gm/L) | (cl/L) | (ml/L) | (µg at./L) | | | |
| 0 | 27.50 | 18.28 | 33.03 | 4.46 | 21.10 | 669.7 | .03 | -0 | -0 | -0 | -0 |
| 49 | 26.38 | 18.28 | 33.03 | 4.41 | 21.45 | 635.7 | .16 | -0 | -0 | -0 | -0 |
| 74 | 25.81 | 18.66 | 33.71 | 4.13 | 22.14 | 569.4 | .46 | -0 | -0 | -0 | -0 |
| 99 | 19.31 | 18.73 | 33.84 | 1.78 | 24.08 | 384.8 | 3.34 | -0 | -0 | -0 | -0 |
| 149 | 13.14 | 19.04 | 34.40 | .21 | 25.92 | 209.5 | 5.53 | -0 | -0 | -0 | -0 |
| 200 | 12.45 | 19.29 | 34.85 | .33 | 26.40 | 163.3 | 5.48 | -0 | -0 | -0 | -0 |
| 299 | 11.04 | 19.20 | 34.69 | .17 | 26.54 | 150.0 | 5.83 | -0 | -0 | -0 | -0 |
| 393 | 9.75 | 19.12 | 34.54 | .18 | 26.66 | 139.3 | 6.00 | -0 | -0 | -0 | -0 |
| 576 | 7.16 | 19.12f) | 34.54 | .22 | 27.06 | 101.3 | 6.34 | -0 | -0 | -0 | -0 |

INTERPOLATED AND COMPUTED VALUES AT STANDARD DEPTHS

| Z | T | Cl | S | $\sigma_T$ | $\delta_T$ | $\delta$ | $\Delta D_{Z/0}$ | $\Delta D_{Z/Z\,MAX}$ | $Q_Z$ |
|---|---|---|---|---|---|---|---|---|---|
| (m) | (°C) | (‰) | (‰) | (gm/L) | (cl/T) | (cl/T) | (dyn m) | (dyn m) | (m-dynm) |
| 0 | 27.50 | 18.28 | 33.03 | 21.09 | 669.7 | 669.8 | 0 | 1.407 | 281.5 |
| 10 | 27.37 | 18.28 | 33.02 | 21.13 | 665.9 | 666.4 | .067 | 1.340 | 267.7 |
| 20 | 27.21 | 18.28 | 33.02 | 21.19 | 661.0 | 661.9 | .133 | 1.274 | 254.7 |
| 30 | 27.01 | 18.28 | 33.02 | 21.25 | 654.7 | 656.1 | .199 | 1.208 | 242.2 |
| 50 | 26.36 | 18.29 | 33.04 | 21.47 | 633.9 | 636.0 | .328 | 1.079 | 219.4 |
| 75 | 25.63 | 18.66 | 33.72 | 22.20 | 563.6 | 566.7 | .479 | .929 | 194.3 |
| 100 | 19.16 | 18.73 | 33.85 | 24.12 | 380.5 | 384.0 | .598 | .810 | 172.6 |
| 150 | 13.12 | 19.05 | 34.41 | 25.93 | 208.4 | 212.6 | .747 | .661 | 135.8 |
| 200 | 12.45 | 19.29 | 34.85 | 26.40 | 163.3 | 168.6 | .842 | .565 | 105.2 |
| 250 | 11.67 | 19.24 | 34.75 | 26.48 | 155.9 | 162.2 | .925 | .483 | 79.0 |
| 300 | 11.02 | 19.20 | 34.68 | 26.54 | 149.9 | 157.1 | 1.005 | .403 | 56.8 |
| 400 | 9.63 | 19.12 | 34.54 | 26.67 | 137.5 | 146.1 | 1.156 | .251 | 24.1 |
| 500 | 8.12 | 19.11 | 34.53 | 26.91 | 115.4 | 124.6 | 1.291 | .116 | 5.8 |
| 600 | 6.88 | 19.12 | 34.55 | 27.10 | 97.3 | 106.9 | 1.407 | 0 | 0 |

H 230

| STATION | DATE | TIME | LATITUDE | LONGITUDE | D |
|---|---|---|---|---|---|
| H 230 | JAN 22, 1964 | 0806-0910 | 14° 58.5'N | 103° 49.1'W | 35 |

OBSERVED AND COMPUTED VALUES AT OBSERVED DEPTHS

| Z (m) | T (°C) | Cl (‰) | S (‰) | $O_2$ (ml/L) | $\sigma_T$ (gm/L) | $\delta_T$ (cl/L) | AOU (ml/L) | $PO_4$ (μg at./L) | $NO_3$ (μg at./L) | $SiO_4$ (μg at./L) | $NO_2$ (μg at./L) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 0 | 27.50 | 999.00 | 999.00 | 4.46 | 999.00 | 999.0 | 999.00 | -0 | -0 | -0 | -0 |
| 50 | 27.30 | 999.00 | 999.00 | 4.46 | 999.00 | 999.0 | 999.00 | -0 | -0 | -0 | -0 |
| 75 | 20.02 | 999.00 | 999.00 | 1.59 | 999.00 | 999.0 | 999.00 | -0 | -0 | -0 | -0 |
| 100 | 16.31 | 999.00 | 999.00 | .21 | 999.00 | 999.0 | 999.00 | -0 | -0 | -0 | -0 |
| 150 | 12.72 | 999.00 | 999.00 | .12 | 999.00 | 999.0 | 999.00 | -0 | -0 | -0 | -0 |
| 198 | 12.22 | 999.00 | 999.00 | .13 | 999.00 | 999.0 | 999.00 | -0 | -0 | -0 | -0 |
| 297 | 11.07 | 999.00 | 999.00 | .20 | 999.00 | 999.0 | 999.00 | -0 | -0 | -0 | -0 |
| 390 | 9.66 | 999.00 | 999.00 | .16 | 999.00 | 999.0 | 999.00 | -0 | -0 | -0 | -0 |
| 574 | 6.89 | 999.00 | 999.00 | .17 | 999.00 | 999.0 | 999.00 | -0 | -0 | -0 | -0 |

INTERPOLATED AND COMPUTED VALUES AT STANDARD DEPTHS

| Z (m) | T (°C) | Cl (‰) | S (‰) | $\sigma_T$ (gm/L) | $\delta_T$ (cl/T) | $\delta$ (cl/T) | $\Delta D_{Z/0}$ (dyn m) | $\Delta D_{Z/Z MAX}$ (dyn m) | $Q_Z$ (m-dyn m) |
|---|---|---|---|---|---|---|---|---|---|
| 0 | 27.50 | | | | | | | | |
| 10 | 27.48 | | | | | | | | |
| 20 | 27.45 | | | | | | | | |
| 30 | 27.41 | | | | | | | | |
| 50 | 27.30 | | | | | | | | |
| 75 | 20.02 | | | | | | | | |
| 100 | 16.31 | | | | | | | | |
| 150 | 12.72 | | | | | | | | |
| 200 | 12.19 | | | | | | | | |
| 250 | 11.56 | | | | | | | | |
| 300 | 11.02 | | | | | | | | |
| 400 | 9.48 | | | | | | | | |
| 500 | 7.88 | | | | | | | | |
| 600 | 6.57 | | | | | | | | |

H 235

| STATION | DATE | TIME | LATITUDE | LONGITUDE | D |
|---|---|---|---|---|---|
| H 235 | JAN 31, 1964 | 2015-2115 | 15° 24.0'N | 108° 14.5'W | |

OBSERVED AND COMPUTED VALUES AT OBSERVED DEPTHS

| Z (m) | T (°C) | Cl (‰) | S (‰) | $O_2$ (ml/L) | $\sigma_T$ (gm/L) | $\delta_T$ (cl/L) | AOU (ml/L) | $PO_4$ (μg at./L) | $NO_3$ (μg at./L) | $SiO_4$ (μg at./L) | $NO_2$ (μg at./L) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 0 | 26.90 | 18.44 | 33.31 | 4.41 | 21.50 | 630.6 | .12 | -0 | -0 | -0 | -0 |
| 49 | 26.98 | 18.57 | 33.55 | 4.49 | 21.65 | 616.1 | .03 | -0 | -0 | -0 | -0 |
| 73 | 25.38 | 18.85 | 34.05 | 3.75 | 22.53 | 532.0 | .87 | -0 | -0 | -0 | -0 |
| 97 | 18.37 | 19.11 | 34.52 | 1.18 | 24.84 | 312.4 | 4.00 | -0 | -0 | -0 | -0 |
| 146 | 13.56 | 19.22 | 34.72 | .19 | 26.08 | 193.7 | 5.49 | -0 | -0 | -0 | -0 |
| 194 | 12.19 | 19.24 | 34.76 | .11 | 26.38 | 165.1 | 5.74 | -0 | -0 | -0 | -0 |
| 298 | 10.76 | 19.20 | 34.69 | .15 | 26.59 | 145.2 | 5.88 | -0 | -0 | -0 | -0 |
| 391 | 9.47 | 19.16 | 34.61 | .16 | 26.76 | 129.5 | 6.05 | -0 | -0 | -0 | -0 |
| 573 | 6.92 | 19.12 | 34.54 | .22 | 27.09 | 98.2 | 6.38 | -0 | -0 | -0 | -0 |

INTERPOLATED AND COMPUTED VALUES AT STANDARD DEPTHS

| Z (m) | T (°C) | Cl (‰) | S (‰) | $\sigma_T$ (gm/L) | $\delta_T$ (cl/T) | $\delta$ (cl/T) | $\Delta D_{Z/0}$ (dyn m) | $\Delta D_{Z/Z MAX}$ (dyn m) | $Q_Z$ (m-dyn m) |
|---|---|---|---|---|---|---|---|---|---|
| 0 | 26.90 | 18.44 | 33.31 | 21.50 | 630.6 | 630.7 | 0 | 1.317 | 265.9 |
| 10 | 26.95 | 18.46 | 33.36 | 21.52 | 629.0 | 629.5 | .063 | 1.254 | 253.1 |
| 20 | 26.96 | 18.48 | 33.39 | 21.54 | 626.9 | 627.8 | .126 | 1.191 | 240.8 |
| 30 | 26.97 | 18.51 | 33.43 | 21.57 | 624.2 | 625.6 | .189 | 1.129 | 229.2 |
| 50 | 26.93 | 18.57 | 33.56 | 21.67 | 614.1 | 616.2 | .313 | 1.004 | 207.9 |
| 75 | 24.93 | 18.86 | 34.07 | 22.68 | 517.9 | 521.0 | .455 | .862 | 184.6 |
| 100 | 18.01 | 19.11 | 34.53 | 24.93 | 303.6 | 307.0 | .558 | .759 | 164.3 |
| 150 | 13.43 | 19.22 | 34.72 | 26.11 | 191.0 | 195.3 | .684 | .633 | 129.5 |
| 200 | 12.09 | 19.24 | 34.75 | 26.40 | 163.7 | 168.9 | .775 | .542 | 100.1 |
| 250 | 11.35 | 19.21 | 34.71 | 26.51 | 153.4 | 159.5 | .857 | .460 | 75.1 |
| 300 | 10.73 | 19.20 | 34.68 | 26.60 | 144.9 | 151.9 | .935 | .382 | 54.0 |
| 400 | 9.32 | 19.16 | 34.61 | 26.78 | 127.6 | 136.0 | 1.079 | .238 | 23.0 |
| 500 | 7.83 | 19.13 | 34.56 | 26.97 | 109.3 | 118.3 | 1.206 | .111 | 5.6 |
| 600 | 6.61 | 19.12 | 34.54 | 27.13 | 94.4 | 103.7 | 1.317 | 0 | 0 |

| STATION | DATE | TIME | LATITUDE | LONGITUDE | D |
|---|---|---|---|---|---|
| H 238 | FEB 1, 1964 | 2015-2108 | 14° 01.5'N | 109° 54.8'W | |

OBSERVED AND COMPUTED VALUES AT OBSERVED DEPTHS

| Z | T | Cl | S | $O_2$ | $\sigma_T$ | $\delta_T$ | AOU | $PO_4$ | $NO_3$ | $SiO_4$ | $NO_2$ |
|---|---|---|---|---|---|---|---|---|---|---|---|
| (m) | (°C) | (‰) | (‰) | (ml/L) | (gm/L) | (cl/L) | (ml/L) | (µg at./L) | | | |
| 0 | 26.80 | 18.33 | 33.12 | 4.59 | 21.39 | 641.9 | -.05 | -0 | -0 | -0 | -0 |
| 50 | 26.60 | 18.33 | 33.12 | 4.61 | 21.45 | 635.8 | -.05 | -0 | -0 | -0 | -0 |
| 74 | 20.08 | 19.09 | 34.49 | 1.33 | 24.37 | 356.7 | 3.70 | -0 | -0 | -0 | -0 |
| 99 | 14.94 | 19.22 | 34.72 | .20 | 25.79 | 221.6 | 5.33 | -0 | -0 | -0 | -0 |
| 149 | 12.60 | 19.25 | 34.78 | .23 | 26.32 | 171.4 | 5.56 | -0 | -0 | -0 | -0 |
| 200 | 12.18 | 19.26 | 34.79 | .21 | 26.41 | 162.3 | 5.63 | -0 | -0 | -0 | -0 |
| 300 | 10.89 | 19.23 | 34.74 | .16 | 26.61 | 143.5 | 5.85 | -0 | -0 | -0 | -0 |
| 392 | 9.70 | 19.17 | 34.63 | .13 | 26.74 | 131.8 | 6.05 | -0 | -0 | -0 | -0 |
| 581 | 7.04 | 19.12 | 34.54 | .22 | 27.07 | 99.7 | 6.36 | -0 | -0 | -0 | -0 |

INTERPOLATED AND COMPUTED VALUES AT STANDARD DEPTHS

| Z (m) | T (°C) | Cl (‰) | S (‰) | $\sigma_T$ (gm/L) | $\delta_T$ (cl/T) | $\delta$ (cl/T) | $\Delta D_{Z/0}$ (dyn m) | $\Delta D_{Z/Z\,MAX}$ (dyn m) | $Q_Z$ (m-dynm) |
|---|---|---|---|---|---|---|---|---|---|
| 0 | 26.80 | 18.33 | 33.12 | 21.39 | 641.9 | 642.0 | 0 | 1.249 | 260.8 |
| 10 | 26.78 | 18.33 | 33.12 | 21.39 | 641.2 | 641.7 | .064 | 1.185 | 248.6 |
| 20 | 26.75 | 18.33 | 33.12 | 21.40 | 640.4 | 641.3 | .128 | 1.120 | 237.1 |
| 30 | 26.71 | 18.33 | 33.12 | 21.41 | 639.3 | 640.6 | .192 | 1.056 | 226.2 |
| 50 | 26.60 | 18.33 | 33.12 | 21.45 | 635.8 | 638.0 | .320 | .928 | 206.4 |
| 75 | 19.84 | 19.09 | 34.49 | 24.43 | 350.5 | 353.2 | .444 | .805 | 184.7 |
| 100 | 14.88 | 19.22 | 34.72 | 25.80 | 220.4 | 223.4 | .516 | .732 | 165.5 |
| 150 | 12.59 | 19.25 | 34.78 | 26.32 | 171.2 | 175.2 | .616 | .633 | 131.4 |
| 200 | 12.18 | 19.26 | 34.79 | 26.41 | 162.3 | 167.5 | .702 | .547 | 101.9 |
| 250 | 11.47 | 19.24 | 34.76 | 26.52 | 151.9 | 158.1 | .783 | .466 | 76.6 |
| 300 | 10.89 | 19.23 | 34.74 | 26.61 | 143.5 | 150.6 | .860 | .388 | 55.2 |
| 400 | 9.56 | 19.17 | 34.62 | 26.75 | 130.2 | 138.7 | 1.005 | .244 | 23.6 |
| 500 | 8.06 | 19.13 | 34.56 | 26.94 | 112.0 | 121.2 | 1.135 | .114 | 5.7 |
| 600 | 6.82 | 19.12 | 34.54 | 27.10 | 97.1 | 106.7 | 1.249 | 0 | 0 |

| STATION | DATE | TIME | LATITUDE | LONGITUDE | D |
|---|---|---|---|---|---|
| H 244 | FEB 2, 1964 | 2015-2107 | 11° 16.5'N | 112° 55.4'W | |

OBSERVED AND COMPUTED VALUES AT OBSERVED DEPTHS

| Z | T | Cl | S | $O_2$ | $\sigma_T$ | $\delta_T$ | AOU | $PO_4$ | $NO_3$ | $SiO_4$ | $NO_2$ |
|---|---|---|---|---|---|---|---|---|---|---|---|
| (m) | (°C) | (‰) | (‰) | (ml/L) | (gm/L) | (cl/L) | (ml/L) | (µg at./L) | | | |
| 0 | 26.80 | 18.31 | 33.08 | 4.58 | 21.36 | 644.5 | -.04 | -0 | -0 | -0 | -0 |
| 50 | 24.12 | 18.75 | 33.87 | 3.18 | 22.78 | 508.8 | 1.54 | -0 | -0 | -0 | -0 |
| 75 | 15.21 | 18.26 | 32.99 | .41 | 24.40 | 353.9 | 5.15 | -0 | -0 | -0 | -0 |
| 100 | 13.67 | 19.28 | 34.83 | .22 | 26.14 | 188.0 | 5.44 | -0 | -0 | -0 | -0 |
| 150 | 12.04 | 19.26 | 34.79 | .29 | 26.44 | 159.8 | 5.57 | -0 | -0 | -0 | -0 |
| 208 | 11.39 | 19.25 | 34.78 | .38 | 26.55 | 149.5 | 5.57 | -0 | -0 | -0 | -0 |
| 306 | 10.42 | 19.22 | 34.72 | .24 | 26.68 | 136.9 | 5.84 | -0 | -0 | -0 | -0 |
| 398 | 9.57 | 19.20 | 34.69 | .17 | 26.80 | 125.7 | 6.02 | -0 | -0 | -0 | -0 |
| 586 | 7.13 | 19.15 | 34.60 | .28 | 27.10 | 96.9 | 6.28 | -0 | -0 | -0 | -0 |

INTERPOLATED AND COMPUTED VALUES AT STANDARD DEPTHS

| Z (m) | T (°C) | Cl (‰) | S (‰) | $\sigma_T$ (gm/L) | $\delta_T$ (cl/T) | $\delta$ (cl/T) | $\Delta D_{Z/0}$ (dyn m) | $\Delta D_{Z/Z\,MAX}$ (dyn m) | $Q_Z$ (m-dynm) |
|---|---|---|---|---|---|---|---|---|---|
| 0 | 26.80 | 18.31 | 33.08 | 21.36 | 644.5 | 644.6 | 0 | 1.167 | 249.0 |
| 10 | 26.50 | 18.36 | 33.16 | 21.52 | 629.4 | 629.9 | .064 | 1.103 | 237.6 |
| 20 | 26.13 | 18.42 | 33.27 | 21.71 | 610.6 | 611.5 | .126 | 1.041 | 226.9 |
| 30 | 25.65 | 18.49 | 33.41 | 21.96 | 586.3 | 587.6 | .186 | .981 | 216.8 |
| 50 | 24.12 | 18.75 | 33.87 | 22.77 | 508.8 | 510.9 | .296 | .872 | 198.3 |
| 75 | 15.21 | 18.26 | 32.99 | 24.40 | 353.9 | 356.3 | .404 | .763 | 177.8 |
| 100 | 13.67 | 19.28 | 34.83 | 26.14 | 188.0 | 190.9 | .472 | .695 | 159.6 |
| 150 | 12.04 | 19.26 | 34.79 | 26.44 | 159.8 | 163.7 | .561 | .606 | 127.1 |
| 200 | 11.47 | 19.25 | 34.78 | 26.53 | 150.7 | 155.7 | .641 | .526 | 98.8 |
| 250 | 10.93 | 19.23 | 34.75 | 26.61 | 143.5 | 149.4 | .717 | .450 | 74.4 |
| 300 | 10.47 | 19.22 | 34.72 | 26.67 | 137.5 | 144.4 | .791 | .377 | 53.7 |
| 400 | 9.54 | 19.20 | 34.68 | 26.80 | 125.4 | 133.9 | .930 | .237 | 23.0 |
| 500 | 8.13 | 19.16 | 34.62 | 26.98 | 108.7 | 118.0 | 1.056 | .111 | 5.6 |
| 600 | 6.98 | 19.15 | 34.59 | 27.12 | 95.1 | 104.9 | 1.167 | 0 | 0 |

| STATION | DATE | TIME | LATITUDE | LONGITUDE | D |
|---|---|---|---|---|---|
| H 247 | FEB 3, 1964 | 2015-2105 | 10° 29.0'N | 113° 58.6'W | |

OBSERVED AND COMPUTED VALUES AT OBSERVED DEPTHS

| Z (m) | T (°C) | Cl (‰) | S (‰) | $O_2$ (ml/L) | $\sigma_T$ (gm/L) | $\delta_T$ (cl/L) | AOU (ml/L) | $PO_4$ (µg at./L) | $NO_3$ (µg at./L) | $SiO_4$ (µg at./L) | $NO_2$ (µg at./L) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 0 | 27.10 | 18.45 | 33.33 | 4.57 | 21.45 | 635.4 | -.06 | -0 | -0 | -0 | -0 |
| 49 | 26.98 | 18.65 | 33.69 | 4.60 | 21.76 | 605.7 | -.09 | -0 | -0 | -0 | -0 |
| 74 | 15.13 | 19.20 | 34.69 | .55 | 25.72 | 228.2 | 4.96 | -0 | -0 | -0 | -0 |
| 99 | 13.17 | 19.24 | 34.76 | .24 | 26.19 | 183.5 | 5.49 | -0 | -0 | -0 | -0 |
| 148 | 11.99 | 19.26 | 34.79 | .39 | 26.45 | 158.8 | 5.48 | -0 | -0 | -0 | -0 |
| 208 | 11.25 | 19.25 | 34.78 | .28 | 26.57 | 147.0 | 5.68 | -0 | -0 | -0 | -0 |
| 313 | 10.25 | 19.20 | 34.69 | .25 | 26.68 | 136.7 | 5.85 | -0 | -0 | -0 | -0 |
| 415 | 9.18 | 19.17 | 34.63 | .16 | 26.82 | 123.7 | 6.09 | -0 | -0 | -0 | -0 |
| 590 | 6.80 | 19.16 | 34.61 | .23 | 27.16 | 91.2 | 6.38 | -0 | -0 | -0 | -0 |

INTERPOLATED AND COMPUTED VALUES AT STANDARD DEPTHS

| Z (m) | T (°C) | Cl (‰) | S (‰) | $\sigma_T$ (gm/L) | $\delta_T$ (cl/T) | $\delta$ (cl/T) | $\Delta D_{Z/0}$ (dyn m) | $\Delta D_{Z/Z\,MAX}$ (dyn m) | $Q_Z$ (m-dynm) |
|---|---|---|---|---|---|---|---|---|---|
| 0 | 27.10 | 18.45 | 33.33 | 21.45 | 635.4 | 635.5 | 0 | 1.152 | 244.3 |
| 10 | 27.09 | 18.47 | 33.37 | 21.49 | 632.0 | 632.5 | .063 | 1.089 | 233.1 |
| 20 | 27.07 | 18.50 | 33.42 | 21.53 | 627.8 | 628.7 | .126 | 1.026 | 222.6 |
| 30 | 27.05 | 18.54 | 33.49 | 21.59 | 622.3 | 623.6 | .189 | .963 | 212.6 |
| 50 | 26.73 | 18.66 | 33.71 | 21.85 | 596.9 | 599.0 | .311 | .841 | 194.6 |
| 75 | 15.04 | 19.20 | 34.69 | 25.74 | 226.1 | 228.5 | .415 | .737 | 174.8 |
| 100 | 13.14 | 19.24 | 34.76 | 26.20 | 182.9 | 185.7 | .467 | .686 | 157.0 |
| 150 | 11.96 | 19.26 | 34.79 | 26.45 | 158.4 | 162.3 | .554 | .599 | 124.9 |
| 200 | 11.34 | 19.25 | 34.78 | 26.56 | 148.4 | 153.3 | .632 | .520 | 97.0 |
| 250 | 10.80 | 19.23 | 34.73 | 26.62 | 142.4 | 148.3 | .708 | .444 | 72.9 |
| 300 | 10.35 | 19.20 | 34.69 | 26.67 | 137.8 | 144.6 | .781 | .371 | 52.5 |
| 400 | 9.32 | 19.17 | 34.64 | 26.80 | 125.4 | 133.7 | .920 | .232 | 22.3 |
| 500 | 7.92 | 19.16 | 34.61 | 27.00 | 106.5 | 115.6 | 1.045 | .107 | 5.4 |
| 600 | 6.69 | 19.16 | 34.61 | 27.18 | 89.7 | 99.1 | 1.152 | 0 | 0 |

H 247

| STATION | DATE | TIME | LATITUDE | LONGITUDE | D |
|---|---|---|---|---|---|
| H 253 | FEB 4, 1964 | 2015-2101 | 07° 28.9'N | 116° 37.0'W | |

OBSERVED AND COMPUTED VALUES AT OBSERVED DEPTHS

| Z (m) | T (°C) | Cl (‰) | S (‰) | $O_2$ (ml/L) | $\sigma_T$ (gm/L) | $\delta_T$ (cl/L) | AOU (ml/L) | $PO_4$ (µg at./L) | $NO_3$ (µg at./L) | $SiO_4$ (µg at./L) | $NO_2$ (µg at./L) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 0 | 27.10 | 18.71 | 33.80 | 4.62 | 21.81 | 601.6 | -.12 | -0 | -0 | -0 | -0 |
| 50 | 27.10 | 18.96 | 34.25 | 4.61 | 22.15 | 569.1 | -.12 | -0 | -0 | -0 | -0 |
| 75 | 20.64 | 19.20 | 34.69 | 4.19 | 24.37 | 356.5 | .78 | -0 | -0 | -0 | -0 |
| 100 | 13.76 | 19.21 | 34.70 | .62 | 26.03 | 199.0 | 5.04 | -0 | -0 | -0 | -0 |
| 150 | 11.93 | 19.24 | 34.76 | .57 | 26.43 | 160.4 | 5.31 | -0 | -0 | -0 | -0 |
| 208 | 11.15 | 19.23 | 34.74 | .62 | 26.57 | 147.9 | 5.36 | -0 | -0 | -0 | -0 |
| 308 | 10.00 | 19.21 | 34.70 | .48 | 26.74 | 131.3 | 5.65 | -0 | -0 | -0 | -0 |
| 404 | 9.01 | 19.18 | 34.65 | .28 | 26.86 | 119.7 | 6.00 | -0 | -0 | -0 | -0 |
| 586 | 6.89 | 19.15 | 34.60 | .28 | 27.14 | 93.7 | 6.32 | -0 | -0 | -0 | -0 |

INTERPOLATED AND COMPUTED VALUES AT STANDARD DEPTHS

| Z (m) | T (°C) | Cl (‰) | S (‰) | $\sigma_T$ (gm/L) | $\delta_T$ (cl/T) | $\delta$ (cl/T) | $\Delta D_{Z/0}$ (dyn m) | $\Delta D_{Z/Z\,MAX}$ (dyn m) | $Q_Z$ (m-dynm) |
|---|---|---|---|---|---|---|---|---|---|
| 0 | 27.10 | 18.71 | 33.80 | 21.81 | 601.6 | 601.7 | 0 | 1.161 | 243.1 |
| 10 | 27.10 | 18.73 | 33.85 | 21.84 | 598.0 | 598.1 | .060 | 1.101 | 231.8 |
| 20 | 27.10 | 18.77 | 33.91 | 21.89 | 593.5 | 593.5 | .120 | 1.041 | 221.1 |
| 30 | 27.10 | 18.81 | 33.99 | 21.95 | 587.7 | 587.7 | .179 | .982 | 210.9 |
| 50 | 27.10 | 18.96 | 34.25 | 22.14 | 569.1 | 571.3 | .295 | .866 | 192.5 |
| 75 | 20.64 | 19.20 | 34.69 | 24.37 | 356.5 | 359.3 | .411 | .750 | 172.3 |
| 100 | 13.76 | 19.21 | 34.70 | 26.03 | 199.0 | 201.9 | .481 | .680 | 154.4 |
| 150 | 11.93 | 19.24 | 34.76 | 26.43 | 160.4 | 164.3 | .573 | .588 | 122.7 |
| 200 | 11.24 | 19.23 | 34.74 | 26.55 | 149.4 | 154.4 | .652 | .509 | 95.2 |
| 250 | 10.61 | 19.22 | 34.72 | 26.65 | 140.1 | 146.0 | .727 | .434 | 71.7 |
| 300 | 10.08 | 19.21 | 34.71 | 26.73 | 132.4 | 139.1 | .799 | .362 | 51.8 |
| 400 | 9.05 | 19.18 | 34.65 | 26.86 | 120.1 | 128.3 | .932 | .229 | 22.2 |
| 500 | 7.79 | 19.16 | 34.61 | 27.02 | 104.8 | 113.8 | 1.053 | .108 | 5.4 |
| 600 | 6.76 | 19.15 | 34.59 | 27.15 | 92.1 | 101.6 | 1.161 | 0 | 0 |

H 253

| STATION | DATE | TIME | LATITUDE | LONGITUDE | D |
|---|---|---|---|---|---|
| H 255 | FEB 5, 1964 | 2015-2059 | 06° 55.0'N | 117° 27.4'W | |

OBSERVED AND COMPUTED VALUES AT OBSERVED DEPTHS

| Z (m) | T (°C) | Cl (‰) | S (‰) | $O_2$ (ml/L) | $\sigma_T$ (gm/L) | $\delta_T$ (cl/L) | AOU (ml/L) | $PO_4$ (μg at./L) | $NO_3$ (μg at./L) | $SiO_4$ (μg at./L) | $NO_2$ (μg at./L) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 0 | 27.20 | 19.15 | 34.60 | 4.57 | 22.37 | 547.5 | -.10 | -0 | -0 | -0 | -0 |
| 49 | 26.99 | 19.16 | 34.61 | 4.64 | 22.45 | 539.8 | -.16 | -0 | -0 | -0 | -0 |
| 74 | 22.34 | 19.35 | 34.96 | 4.27 | 24.11 | 381.5 | .55 | -0 | -0 | -0 | -0 |
| 99 | 15.33 | 19.28 | 34.83 | 1.97 | 25.79 | 221.9 | 3.51 | -0 | -0 | -0 | -0 |
| 148 | 12.25 | 19.36 | 34.97 | .50 | 26.54 | 150.3 | 5.33 | -0 | -0 | -0 | -0 |
| 197 | 11.67 | 19.33 | 34.92 | .78 | 26.61 | 143.8 | 5.12 | -0 | -0 | -0 | -0 |
| 287 | 10.37 | 19.32 | 34.90 | .66 | 26.83 | 122.7 | 5.41 | -0 | -0 | -0 | -0 |
| 376 | 9.06 | 19.27 | 34.81 | .22 | 26.98 | 108.4 | 6.04 | -0 | -0 | -0 | -0 |
| 556 | 6.95 | 19.26 | 34.79 | .36 | 27.28 | 79.7 | 6.22 | -0 | -0 | -0 | -0 |

INTERPOLATED AND COMPUTED VALUES AT STANDARD DEPTHS

| Z (m) | T (°C) | Cl (‰) | S (‰) | $\sigma_T$ (gm/L) | $\delta_T$ (cl/T) | $\delta$ (cl/T) | $\Delta D_{Z/0}$ (dyn m) | $\Delta D_{Z/Z\,MAX}$ (dyn m) | $Q_Z$ (m-dyn m) |
|---|---|---|---|---|---|---|---|---|---|
| 0 | 27.20 | 19.15 | 34.60 | 22.37 | 547.5 | 547.6 | 0 | 1.082 | 217.7 |
| 10 | 27.18 | 19.15 | 34.60 | 22.38 | 546.7 | 547.2 | .055 | 1.028 | 207.1 |
| 20 | 27.15 | 19.15 | 34.60 | 22.39 | 545.6 | 546.5 | .109 | .973 | 197.1 |
| 30 | 27.11 | 19.15 | 34.60 | 22.41 | 544.1 | 545.5 | .164 | .918 | 187.7 |
| 50 | 26.89 | 19.16 | 34.62 | 22.49 | 536.4 | 538.6 | .272 | .810 | 170.4 |
| 75 | 22.11 | 19.34 | 34.95 | 24.17 | 376.1 | 379.0 | .387 | .695 | 151.6 |
| 100 | 15.25 | 19.28 | 34.83 | 25.80 | 220.1 | 223.2 | .462 | .620 | 135.1 |
| 150 | 12.22 | 19.36 | 34.97 | 26.54 | 150.0 | 154.0 | .557 | .526 | 106.5 |
| 200 | 11.62 | 19.33 | 34.92 | 26.62 | 142.9 | 148.0 | .632 | .450 | 82.1 |
| 250 | 10.85 | 19.32 | 34.91 | 26.75 | 130.4 | 136.4 | .703 | .379 | 61.3 |
| 300 | 10.16 | 19.31 | 34.89 | 26.85 | 120.4 | 127.1 | .769 | .313 | 44.0 |
| 400 | 8.73 | 19.27 | 34.80 | 27.03 | 103.9 | 111.8 | .889 | .194 | 18.7 |
| 500 | 7.52 | 19.26 | 34.79 | 27.20 | 87.5 | 96.2 | .993 | .090 | 4.5 |
| 600 | 6.54 | 19.26 | 34.80 | 27.34 | 74.1 | 83.4 | 1.082 | 0 | 0 |

| STATION | DATE | TIME | LATITUDE | LONGITUDE | D |
|---|---|---|---|---|---|
| H 261 | FEB 6,.1964 | 2010-2052 | 04° 17.0'N | 120° 00.5'W | |

OBSERVED AND COMPUTED VALUES AT OBSERVED DEPTHS

| Z (m) | T (°C) | Cl (‰) | S (‰) | $O_2$ (ml/L) | $\sigma_T$ (gm/L) | $\delta_T$ (cl/L) | AOU (ml/L) | $PO_4$ (μg at./L) | $NO_3$ (μg at./L) | $SiO_4$ (μg at./L) | $NO_2$ (μg at./L) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 0 | 27.00 | 19.28 | 34.83 | 4.57 | 22.61 | 524.5 | -.09 | -0 | -0 | -0 | -0 |
| 50 | 26.92 | 19.27 | 34.81 | 4.56 | 22.62 | 523.4 | -.08 | -0 | -0 | -0 | -0 |
| 75 | 26.95 | 19.28 | 34.83 | 4.58 | 22.63 | 523.0 | -.10 | -0 | -0 | -0 | -0 |
| 100 | 25.69 | 19.43 | 35.10 | 4.07 | 23.23 | 465.7 | .49 | -0 | -0 | -0 | -0 |
| 150 | 13.20 | 19.25 | 34.78 | 2.17 | 26.20 | 182.8 | 3.55 | -0 | -0 | -0 | -0 |
| 204 | 10.90 | 19.28 | 34.83 | 1.85 | 26.68 | 137.0 | 4.16 | -0 | -0 | -0 | -0 |
| 302 | 9.46 | 19.29 | 34.85 | 1.45 | 26.94 | 112.0 | 4.75 | -0 | -0 | -0 | -0 |
| 392 | 8.77 | 19.28 | 34.83 | .83 | 27.04 | 102.7 | 5.47 | -0 | -0 | -0 | -0 |
| 585 | 6.85 | 19.24 | 34.76 | .72 | 27.27 | 81.1 | 5.88 | -0 | -0 | -0 | -0 |

INTERPOLATED AND COMPUTED VALUES AT STANDARD DEPTHS

| Z (m) | T (°C) | Cl (‰) | S (‰) | $\sigma_T$ (gm/L) | $\delta_T$ (cl/T) | $\delta$ (cl/T) | $\Delta D_{Z/0}$ (dyn m) | $\Delta D_{Z/Z\,MAX}$ (dyn m) | $Q_Z$ (m-dyn m) |
|---|---|---|---|---|---|---|---|---|---|
| 0 | 27.00 | 19.28 | 34.83 | 22.61 | 524.5 | 524.7 | 0 | 1.208 | 231.6 |
| 10 | 26.99 | 19.28 | 34.83 | 22.61 | 524.4 | 524.9 | .052 | 1.156 | 219.7 |
| 20 | 26.98 | 19.28 | 34.83 | 22.61 | 524.3 | 525.2 | .105 | 1.103 | 208.4 |
| 30 | 26.97 | 19.28 | 34.82 | 22.62 | 524.1 | 525.4 | .158 | 1.051 | 197.7 |
| 50 | 26.92 | 19.27 | 34.81 | 22.62 | 523.4 | 525.5 | .263 | .946 | 177.7 |
| 75 | 26.95 | 19.28 | 34.83 | 22.63 | 523.0 | 526.2 | .394 | .814 | 155.7 |
| 100 | 25.69 | 19.43 | 35.10 | 23.23 | 465.7 | 469.8 | .519 | .690 | 136.9 |
| 150 | 13.20 | 19.25 | 34.78 | 26.20 | 182.8 | 187.0 | .683 | .526 | 106.5 |
| 200 | 11.05 | 19.28 | 34.82 | 26.65 | 139.9 | 144.8 | .766 | .443 | 82.3 |
| 250 | 10.15 | 19.28 | 34.84 | 26.82 | 124.0 | 129.7 | .834 | .374 | 61.9 |
| 300 | 9.48 | 19.29 | 34.85 | 26.94 | 112.4 | 118.8 | .896 | .312 | 44.7 |
| 400 | 8.67 | 19.28 | 34.83 | 27.05 | 101.6 | 109.5 | 1.011 | .198 | 19.3 |
| 500 | 7.60 | 19.25 | 34.78 | 27.18 | 89.6 | 98.4 | 1.115 | .094 | 4.7 |
| 600 | 6.73 | 19.24 | 34.75 | 27.28 | 79.7 | 89.2 | 1.208 | 0 | 0 |

| STATION | DATE | TIME | LATITUDE | LONGITUDE | D |
|---|---|---|---|---|---|
| H 264 | FEB 7, 1964 | 2010-2102 | 03° 29.2'N | 121° 03.5'W | |

OBSERVED AND COMPUTED VALUES AT OBSERVED DEPTHS

| Z (m) | T (°C) | Cl (‰) | S (‰) | $O_2$ (ml/L) | $\sigma_T$ (gm/L) | $\delta_T$ (cl/L) | AOU (ml/L) | $PO_4$ (µg at./L) | $NO_3$ | $SiO_4$ | $NO_2$ |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 0 | 26.80 | 19.23 | 34.74 | 4.59 | 22.61 | 524.9 | -.10 | -0 | -0 | -0 | -0 |
| 50 | 26.83 | 19.22 | 34.72 | 4.60 | 22.58 | 527.2 | -.11 | -0 | -0 | -0 | -0 |
| 74 | 26.76 | 19.24 | 34.76 | 4.43 | 22.63 | 522.4 | .07 | -0 | -0 | -0 | -0 |
| 99 | 23.10 | 19.39 | 35.03 | 3.63 | 23.95 | 397.0 | 1.13 | -0 | -0 | -0 | -0 |
| 149 | 13.97 | 19.34 | 34.94 | 1.58 | 26.16 | 186.0 | 4.05 | -0 | -0 | -0 | -0 |
| 224 | 12.97 | 999.00 | 999.00 | 1.45 | 999.00 | 999.0 | 999.00 | -0 | -0 | -0 | -0 |
| 318 | 11.24 | 19.26 | 34.79 | .62 | 26.59 | 145.5 | 5.34 | -0 | -0 | -0 | -0 |
| 405 | 9.40 | 19.18 | 34.65 | 1.12 | 26.80 | 125.7 | 5.10 | -0 | -0 | -0 | -0 |
| 587 | 6.43 | 19.21 | 34.70 | 1.50 | 27.28 | 79.8 | 5.17 | -0 | -0 | -0 | -0 |

INTERPOLATED AND COMPUTED VALUES AT STANDARD DEPTHS

H 264

| Z (m) | T (°C) | Cl (‰) | S (‰) | $\sigma_T$ (gm/L) | $\delta_T$ (cl/T) | $\delta$ (cl/T) | $\Delta D_{Z/0}$ (dyn m) | $\Delta D_{Z/Z\,MAX}$ (dyn m) | $Q_Z$ (m-dynm) |
|---|---|---|---|---|---|---|---|---|---|
| 0 | 26.80 | 19.23 | 34.74 | 22.61 | 524.9 | 525.1 | 0 | 1.279 | 259.8 |
| 10 | 26.82 | 19.22 | 34.73 | 22.59 | 526.3 | 526.8 | .053 | 1.226 | 247.3 |
| 20 | 26.82 | 19.22 | 34.73 | 22.59 | 526.7 | 527.6 | .105 | 1.174 | 235.3 |
| 30 | 26.83 | 19.22 | 34.72 | 22.59 | 526.9 | 528.2 | .158 | 1.121 | 223.8 |
| 50 | 26.83 | 19.22 | 34.72 | 22.58 | 527.2 | 529.3 | .264 | 1.015 | 202.4 |
| 75 | 26.68 | 19.24 | 34.76 | 22.66 | 519.7 | 522.8 | .395 | .884 | 178.7 |
| 100 | 22.97 | 19.39 | 35.02 | 23.98 | 393.7 | 397.6 | .510 | .769 | 158.0 |
| 150 | 13.95 | 19.34 | 34.94 | 26.17 | 185.6 | 190.0 | .657 | .622 | 123.3 |
| 200 | 13.25 | 19.35 | 34.96 | 26.33 | 170.3 | 175.8 | .749 | .530 | 94.5 |
| 250 | 12.43 | 19.32 | 34.91 | 26.45 | 158.4 | 164.9 | .834 | .445 | 70.1 |
| 300 | 11.53 | 19.27 | 34.82 | 26.56 | 148.6 | 156.1 | .914 | .365 | 49.9 |
| 400 | 9.49 | 19.18 | 34.66 | 26.79 | 126.8 | 135.2 | 1.060 | .219 | 20.7 |
| 500 | 7.71 | 19.19 | 34.67 | 27.07 | 99.6 | 108.5 | 1.182 | .097 | 4.9 |
| 600 | 6.25 | 19.21 | 34.71 | 27.31 | 77.0 | 85.9 | 1.279 | 0 | 0 |

| STATION | DATE | TIME | LATITUDE | LONGITUDE | D |
|---|---|---|---|---|---|
| H 270 | FEB 8, 1964 | 2013-2055 | 00° 27.2'N | 123° 59.5'W | |

OBSERVED AND COMPUTED VALUES AT OBSERVED DEPTHS

| Z (m) | T (°C) | Cl (‰) | S (‰) | $O_2$ (ml/L) | $\sigma_T$ (gm/L) | $\delta_T$ (cl/L) | AOU (ml/L) | $PO_4$ (µg at./L) | $NO_3$ | $SiO_4$ | $NO_2$ |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 0 | 25.60 | 19.28 | 34.83 | 4.63 | 23.05 | 482.6 | -.05 | -0 | -0 | -0 | -0 |
| 48 | 24.93 | 19.29 | 34.85 | 4.54 | 23.27 | 461.7 | .08 | -0 | -0 | -0 | -0 |
| 71 | 23.76 | 19.35 | 34.96 | 4.16 | 23.70 | 420.6 | .55 | -0 | -0 | -0 | -0 |
| 95 | 17.99 | 19.34 | 34.94 | 2.26 | 25.25 | 273.2 | 2.94 | -0 | -0 | -0 | -0 |
| 143 | 12.98 | 19.31 | 34.88 | 1.85 | 26.33 | 170.6 | 3.89 | -0 | -0 | -0 | -0 |
| 200 | 12.53 | 19.31 | 34.88 | 2.12 | 26.42 | 162.1 | 3.68 | -0 | -0 | -0 | -0 |
| 298 | 11.58 | 19.28 | 34.83 | .73 | 26.56 | 148.8 | 5.19 | -0 | -0 | -0 | -0 |
| 392 | 9.39 | 19.21 | 34.70 | .49 | 26.84 | 121.6 | 5.73 | -0 | -0 | -0 | -0 |
| 578 | 6.95 | 19.17 | 34.63 | 1.37 | 27.16 | 91.8 | 5.22 | -0 | -0 | -0 | -0 |

H 270

INTERPOLATED AND COMPUTED VALUES AT STANDARD DEPTHS

| Z (m) | T (°C) | Cl (‰) | S (‰) | $\sigma_T$ (gm/L) | $\delta_T$ (cl/T) | $\delta$ (cl/T) | $\Delta D_{Z/0}$ (dyn m) | $\Delta D_{Z/Z\,MAX}$ (dyn m) | $Q_Z$ (m-dynm) |
|---|---|---|---|---|---|---|---|---|---|
| 0 | 25.60 | 19.28 | 34.83 | 23.05 | 482.6 | 482.7 | 0 | 1.152 | 250.4 |
| 10 | 25.52 | 19.28 | 34.83 | 23.07 | 480.1 | 480.6 | .048 | 1.104 | 239.1 |
| 20 | 25.42 | 19.28 | 34.83 | 23.11 | 477.1 | 478.0 | .096 | 1.056 | 228.3 |
| 30 | 25.30 | 19.28 | 34.84 | 23.15 | 473.1 | 474.4 | .144 | 1.008 | 218.0 |
| 50 | 24.86 | 19.29 | 34.85 | 23.29 | 459.2 | 461.3 | .237 | .915 | 198.8 |
| 75 | 23.02 | 19.34 | 34.94 | 23.91 | 400.9 | 403.9 | .345 | .807 | 177.3 |
| 100 | 17.36 | 19.33 | 34.92 | 25.38 | 260.4 | 263.8 | .429 | .723 | 158.1 |
| 150 | 12.92 | 19.31 | 34.88 | 26.34 | 169.4 | 173.5 | .538 | .614 | 124.7 |
| 200 | 12.53 | 19.31 | 34.88 | 26.41 | 162.1 | 167.5 | .623 | .529 | 96.1 |
| 250 | 12.00 | 19.29 | 34.85 | 26.49 | 154.7 | 161.1 | .706 | .446 | 71.8 |
| 300 | 11.53 | 19.28 | 34.83 | 26.56 | 148.2 | 155.6 | .785 | .367 | 51.4 |
| 400 | 9.26 | 19.21 | 34.70 | 26.86 | 120.0 | 128.3 | .927 | .225 | 21.8 |
| 500 | 7.86 | 19.18 | 34.65 | 27.04 | 102.9 | 112.0 | 1.047 | .105 | 5.3 |
| 600 | 6.72 | 19.17 | 34.63 | 27.19 | 89.0 | 98.4 | 1.152 | 0 | 0 |

| STATION | DATE | TIME | LATITUDE | LONGITUDE | D |
|---|---|---|---|---|---|
| H 272 | FEB 9, 1964 | 2010-2057 | 00° 03.8'N | 124° 46.0'W | |

OBSERVED AND COMPUTED VALUES AT OBSERVED DEPTHS

| Z (m) | T (°C) | Cl (‰) | S (‰) | $O_2$ (ml/L) | $\sigma_T$ (gm/L) | $\delta_T$ (cl/L) | AOU (ml/L) | $PO_4$ | $NO_3$ | $SiO_4$ | $NO_2$ |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | —— (µg at./L) —— | | | |
| 0 | 25.30 | 19.36 | 34.97 | 4.56 | 23.25 | 463.4 | .03 | -0 | -0 | -0 | -0 |
| 49 | 24.70 | 19.35 | 34.96 | 4.47 | 23.42 | 447.3 | .17 | -0 | -0 | -0 | -0 |
| 74 | 24.19 | 19.36 | 34.97 | 4.32 | 23.59 | 431.4 | .36 | -0 | -0 | -0 | -0 |
| 98 | 21.82 | 19.33 | 34.92 | 3.30 | 24.23 | 370.2 | 1.56 | -0 | -0 | -0 | -0 |
| 147 | 13.39 | 19.29 | 34.85 | 2.67 | 26.21 | 181.2 | 3.03 | -0 | -0 | -0 | -0 |
| 206 | 12.65 | 19.29 | 34.85 | 2.22 | 26.36 | 167.0 | 3.56 | -0 | -0 | -0 | -0 |
| 300 | 11.38 | 19.26 | 34.79 | .79 | 26.56 | 148.0 | 5.16 | -0 | -0 | -0 | -0 |
| 396 | 9.51 | 19.20 | 34.69 | .55 | 26.81 | 124.8 | 5.65 | -0 | -0 | -0 | -0 |
| 583 | 7.13 | 19.17 | 34.63 | 1.18 | 27.13 | 94.2 | 5.38 | -0 | -0 | -0 | -0 |

INTERPOLATED AND COMPUTED VALUES AT STANDARD DEPTHS

| Z (m) | T (°C) | Cl (‰) | S (‰) | $\sigma_T$ (gm/L) | $\delta_T$ (cl/T) | $\delta$ (cl/T) | $\Delta D_{Z/0}$ (dyn m) | $\Delta D_{Z/Z\,MAX}$ (dyn m) | $Q_Z$ (m-dynm) |
|---|---|---|---|---|---|---|---|---|---|
| 0 | 25.30 | 19.36 | 34.97 | 23.25 | 463.4 | 463.5 | 0 | 1.207 | 261.1 |
| 10 | 25.23 | 19.36 | 34.97 | 23.27 | 461.5 | 462.0 | .046 | 1.161 | 249.2 |
| 20 | 25.15 | 19.36 | 34.97 | 23.29 | 459.2 | 460.1 | .092 | 1.115 | 237.9 |
| 30 | 25.04 | 19.36 | 34.97 | 23.32 | 456.3 | 457.6 | .138 | 1.069 | 226.9 |
| 50 | 24.68 | 19.35 | 34.96 | 23.42 | 446.8 | 448.8 | .229 | .979 | 206.5 |
| 75 | 24.12 | 19.36 | 34.97 | 23.60 | 429.6 | 432.7 | .339 | .868 | 183.4 |
| 100 | 21.56 | 19.32 | 34.91 | 24.29 | 364.3 | 368.1 | .439 | .768 | 162.9 |
| 150 | 13.35 | 19.29 | 34.85 | 26.22 | 180.3 | 184.5 | .577 | .630 | 128.0 |
| 200 | 12.71 | 19.29 | 34.85 | 26.35 | 168.3 | 173.7 | .667 | .541 | 98.7 |
| 250 | 12.00 | 19.27 | 34.82 | 26.47 | 157.2 | 163.6 | .751 | .456 | 73.8 |
| 300 | 11.38 | 19.26 | 34.79 | 26.56 | 148.0 | 155.3 | .831 | .377 | 53.0 |
| 400 | 9.45 | 19.20 | 34.68 | 26.82 | 124.0 | 132.4 | .975 | .233 | 22.5 |
| 500 | 8.08 | 19.18 | 34.64 | 27.00 | 106.4 | 115.6 | 1.099 | .109 | 5.4 |
| 600 | 6.95 | 19.17 | 34.63 | 27.15 | 91.9 | 101.7 | 1.207 | 0 | 0 |

| STATION | DATE | TIME | LATITUDE | LONGITUDE | D |
|---|---|---|---|---|---|
| H 278 | FEB 10, 1964 | 2015-2100 | 02° 56.8'N | 127° 38.2'W | |

OBSERVED AND COMPUTED VALUES AT OBSERVED DEPTHS

| Z (m) | T (°C) | Cl (‰) | S (‰) | $O_2$ (ml/L) | $\sigma_T$ (gm/L) | $\delta_T$ (cl/L) | AOU (ml/L) | $PO_4$ | $NO_3$ | $SiO_4$ | $NO_2$ |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | —— (µg at./L) —— | | | |
| 0 | 25.80 | 19.45 | 35.14 | 4.79 | 23.22 | 466.4 | -.24 | -0 | -0 | -0 | -0 |
| 48 | 25.59 | 19.44 | 35.12 | 4.72 | 23.27 | 461.5 | -.15 | -0 | -0 | -0 | -0 |
| 72 | 25.54 | 19.42 | 35.08 | 4.75 | 23.26 | 462.6 | -.18 | -0 | -0 | -0 | -0 |
| 96 | 23.61 | 19.64 | 35.48 | 4.30 | 24.14 | 378.6 | .40 | -0 | -0 | -0 | -0 |
| 144 | 13.24 | 19.44 | 35.12 | .90 | 26.45 | 158.4 | 4.80 | -0 | -0 | -0 | -0 |
| 202 | 12.71 | 19.33 | 34.92 | 1.01 | 26.41 | 162.9 | 4.76 | -0 | -0 | -0 | -0 |
| 286 | 11.78 | 19.30 | 34.87 | .36 | 26.55 | 149.7 | 5.53 | -0 | -0 | -0 | -0 |
| 376 | 10.06 | 19.25 | 34.78 | .28 | 26.79 | 126.9 | 5.84 | -0 | -0 | -0 | -0 |
| 550 | 7.11 | 19.16 | 34.61 | 1.17 | 27.12 | 95.3 | 5.39 | -0 | -0 | -0 | -0 |

INTERPOLATED AND COMPUTED VALUES AT STANDARD DEPTHS

| Z (m) | T (°C) | Cl (‰) | S (‰) | $\sigma_T$ (gm/L) | $\delta_T$ (cl/T) | $\delta$ (cl/T) | $\Delta D_{Z/0}$ (dyn m) | $\Delta D_{Z/Z\,MAX}$ (dyn m) | $Q_Z$ (m-dynm) |
|---|---|---|---|---|---|---|---|---|---|
| 0 | 25.80 | 19.45 | 35.14 | 23.22 | 466.4 | 466.5 | 0 | 1.196 | 255.1 |
| 10 | 25.78 | 19.45 | 35.13 | 23.22 | 465.8 | 466.3 | .047 | 1.150 | 243.4 |
| 20 | 25.74 | 19.45 | 35.13 | 23.23 | 465.1 | 466.0 | .093 | 1.103 | 232.1 |
| 30 | 25.70 | 19.45 | 35.13 | 23.24 | 464.1 | 465.5 | .140 | 1.056 | 221.3 |
| 50 | 25.59 | 19.44 | 35.12 | 23.27 | 461.6 | 463.7 | .233 | .963 | 201.1 |
| 75 | 25.40 | 19.43 | 35.11 | 23.32 | 456.8 | 459.9 | .348 | .848 | 178.5 |
| 100 | 23.01 | 19.62 | 35.44 | 24.28 | 364.7 | 368.6 | .452 | .744 | 158.6 |
| 150 | 13.18 | 19.43 | 35.09 | 26.45 | 158.9 | 163.1 | .585 | .611 | 124.7 |
| 200 | 12.73 | 19.33 | 34.93 | 26.41 | 162.7 | 168.1 | .667 | .529 | 96.2 |
| 250 | 12.14 | 19.31 | 34.89 | 26.49 | 154.8 | 161.3 | .750 | .446 | 71.8 |
| 300 | 11.48 | 19.29 | 34.85 | 26.59 | 145.8 | 153.2 | .828 | .368 | 51.5 |
| 400 | 9.58 | 19.23 | 34.74 | 26.84 | 121.8 | 130.3 | .970 | .226 | 21.8 |
| 500 | 7.85 | 19.18 | 34.64 | 27.04 | 103.2 | 112.2 | 1.091 | .105 | 5.2 |
| 600 | 6.43 | 19.15 | 34.59 | 27.20 | 88.0 | 97.1 | 1.196 | 0 | 0 |

H 281

| STATION | DATE | TIME | LATITUDE | LONGITUDE | D |
|---|---|---|---|---|---|
| H 281 | FEB 11, 1964 | 2010-2053 | 04° 00.3'S | 128° 53.5'W | |

OBSERVED AND COMPUTED VALUES AT OBSERVED DEPTHS

| Z (m) | T (°C) | Cl (‰) | S (‰) | $O_2$ (ml/L) | $\sigma_T$ (gm/L) | $\delta_T$ (cl/L) | AOU (ml/L) | $PO_4$ (µg at./L) | $NO_3$ (µg at./L) | $SiO_4$ (µg at./L) | $NO_2$ (µg at./L) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 0 | 25.90 | 19.44 | 35.12 | 4.66 | 23.18 | 470.6 | -.11 | -0 | -0 | -0 | -0 |
| 48 | 25.82 | 19.44 | 35.12 | 4.67 | 23.20 | 468.3 | -.12 | -0 | -0 | -0 | -0 |
| 72 | 25.93 | 19.55 | 35.32 | 4.67 | 23.32 | 457.2 | -.13 | -0 | -0 | -0 | -0 |
| 96 | 25.61 | 19.55 | 35.32 | 4.59 | 23.42 | 447.8 | -.03 | -0 | -0 | -0 | -0 |
| 144 | 14.57 | 19.39 | 35.03 | 1.54 | 26.11 | 191.5 | 4.01 | -0 | -0 | -0 | -0 |
| 209 | 12.86 | 19.35 | 34.96 | .68 | 26.41 | 163.0 | 5.08 | -0 | -0 | -0 | -0 |
| 306 | 11.89 | 19.33 | 34.92 | .34 | 26.57 | 147.7 | 5.54 | -0 | -0 | -0 | -0 |
| 419 | 9.91 | 19.26 | 34.79 | .59 | 26.83 | 123.2 | 5.55 | -0 | -0 | -0 | -0 |
| 576 | 7.32 | 19.19 | 34.67 | 1.00 | 27.13 | 94.1 | 5.53 | -0 | -0 | -0 | -0 |

INTERPOLATED AND COMPUTED VALUES AT STANDARD DEPTHS

| Z (m) | T (°C) | Cl (‰) | S (‰) | $\sigma_T$ (gm/L) | $\delta_T$ (cl/T) | $\delta$ (cl/T) | $\Delta D_{Z/O}$ (dyn m) | $\Delta D_{Z/Z\,MAX}$ (dyn m) | $Q_Z$ (m-dynm) |
|---|---|---|---|---|---|---|---|---|---|
| 0 | 25.90 | 19.44 | 35.12 | 23.17 | 470.6 | 470.8 | 0 | 1.256 | 266.8 |
| 10 | 25.85 | 19.43 | 35.10 | 23.18 | 470.4 | 470.9 | .047 | 1.209 | 254.5 |
| 20 | 25.84 | 19.43 | 35.10 | 23.18 | 470.0 | 470.9 | .094 | 1.162 | 242.6 |
| 30 | 25.83 | 19.43 | 35.10 | 23.19 | 469.6 | 470.9 | .141 | 1.115 | 231.2 |
| 50 | 25.83 | 19.45 | 35.13 | 23.21 | 467.7 | 469.8 | .235 | 1.021 | 209.9 |
| 75 | 25.90 | 19.55 | 35.32 | 23.32 | 456.3 | 459.4 | .351 | .905 | 185.8 |
| 100 | 25.05 | 19.53 | 35.27 | 23.55 | 434.5 | 438.6 | .464 | .793 | 164.6 |
| 150 | 14.38 | 19.38 | 35.02 | 26.14 | 188.4 | 192.8 | .622 | .635 | 128.9 |
| 200 | 13.06 | 19.35 | 34.96 | 26.37 | 166.4 | 171.9 | .713 | .544 | 99.4 |
| 250 | 12.40 | 19.34 | 34.94 | 26.48 | 155.9 | 162.4 | .796 | .460 | 74.3 |
| 300 | 11.94 | 19.33 | 34.92 | 26.56 | 148.5 | 156.2 | .876 | .381 | 53.3 |
| 400 | 10.20 | 19.27 | 34.81 | 26.79 | 126.8 | 135.8 | 1.022 | .235 | 22.6 |
| 500 | 8.47 | 19.21 | 34.71 | 27.00 | 107.0 | 116.6 | 1.148 | .108 | 5.4 |
| 600 | 6.99 | 19.18 | 34.66 | 27.17 | 90.3 | 100.1 | 1.256 | 0 | 0 |

H 286

| STATION | DATE | TIME | LATITUDE | LONGITUDE | D |
|---|---|---|---|---|---|
| H 286 | FEB 12, 1964 | 1600-1644 | 06° 33.3'S | 131° 13.5'W | |

OBSERVED AND COMPUTED VALUES AT OBSERVED DEPTHS

| Z (m) | T (°C) | Cl (‰) | S (‰) | $O_2$ (ml/L) | $\sigma_T$ (gm/L) | $\delta_T$ (cl/L) | AOU (ml/L) | $PO_4$ (µg at./L) | $NO_3$ (µg at./L) | $SiO_4$ (µg at./L) | $NO_2$ (µg at./L) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 0 | 26.80 | 19.65 | 35.50 | 4.55 | 23.18 | 470.4 | -.08 | -0 | -0 | -0 | -0 |
| 50 | 26.57 | 19.62 | 35.44 | 4.52 | 23.21 | 467.3 | -.03 | -0 | -0 | -0 | -0 |
| 75 | 26.62 | 19.63 | 35.46 | 4.61 | 23.21 | 467.6 | -.13 | -0 | -0 | -0 | -0 |
| 100 | 25.69 | 19.65 | 35.50 | 4.55 | 23.53 | 437.1 | -.00 | -0 | -0 | -0 | -0 |
| 150 | 22.95 | 19.90 | 35.95 | 4.17 | 24.69 | 326.4 | .57 | -0 | -0 | -0 | -0 |
| 208 | 14.37 | 19.35 | 34.96 | 1.09 | 26.09 | 192.7 | 4.49 | -0 | -0 | -0 | -0 |
| 301 | 11.46 | 19.28 | 34.83 | .53 | 26.58 | 146.7 | 5.40 | -0 | -0 | -0 | -0 |
| 336 | 9.90 | 19.22 | 34.72 | .33 | 26.77 | 128.3 | 5.82 | -0 | -0 | -0 | -0 |

INTERPOLATED AND COMPUTED VALUES AT STANDARD DEPTHS

| Z (m) | T (°C) | Cl (‰) | S (‰) | $\sigma_T$ (gm/L) | $\delta_T$ (cl/T) | $\delta$ (cl/T) | $\Delta D_{Z/O}$ (dyn m) | $\Delta D_{Z/Z\,MAX}$ (dyn m) | $Q_Z$ (m-dynm) |
|---|---|---|---|---|---|---|---|---|---|
| 0 | 26.80 | 19.65 | 35.50 | 23.18 | 470.4 | 470.5 | 0 | .978 | 116.2 |
| 10 | 26.77 | 19.65 | 35.49 | 23.18 | 470.1 | 470.6 | .047 | .931 | 106.7 |
| 20 | 26.74 | 19.64 | 35.48 | 23.18 | 469.7 | 470.6 | .094 | .884 | 97.6 |
| 30 | 26.70 | 19.64 | 35.47 | 23.19 | 469.1 | 470.4 | .141 | .837 | 89.0 |
| 50 | 26.57 | 19.62 | 35.44 | 23.21 | 467.3 | 469.5 | .235 | .743 | 73.2 |
| 75 | 26.62 | 19.63 | 35.46 | 23.21 | 467.6 | 470.7 | .353 | .626 | 56.1 |
| 100 | 25.69 | 19.65 | 35.50 | 23.53 | 437.1 | 441.2 | .467 | .512 | 41.9 |
| 150 | 22.95 | 19.90 | 35.95 | 24.69 | 326.4 | 332.2 | .660 | .318 | 21.1 |
| 200 | 15.49 | 19.39 | 35.04 | 25.91 | 210.2 | 216.3 | .797 | .181 | 8.7 |
| 250 | 12.92 | 19.31 | 34.88 | 26.33 | 169.8 | 176.6 | .895 | .083 | 2.1 |
| 300 | 11.49 | 19.28 | 34.83 | 26.57 | 147.1 | 154.5 | .978 | 0 | 0 |

| STATION | DATE | TIME | LATITUDE | LONGITUDE | D |
|---|---|---|---|---|---|
| H 288 | FEB 13, 1964 | 2010-2111 | 07° 16.6'S | 132° 10.3'W | |

OBSERVED AND COMPUTED VALUES AT OBSERVED DEPTHS

| Z (m) | T (°C) | Cl (‰) | S (‰) | $O_2$ (ml/L) | $\sigma_T$ (gm/L) | $\delta_T$ (cl/L) | AOU (ml/L) | $PO_4$ —— (μg at./L) —— | $NO_3$ | $SiO_4$ | $NO_2$ |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 0 | 26.90 | 19.77 | 35.71 | 4.55 | 23.31 | 457.9 | -.09 | -0 | -0 | -0 | -0 |
| 50 | 26.70 | 19.77 | 35.71 | 4.56 | 23.37 | 451.8 | -.09 | -0 | -0 | -0 | -0 |
| 75 | 26.73 | 19.72 | 35.62 | 4.60 | 23.30 | 459.2 | -.13 | -0 | -0 | -0 | -0 |
| 100 | 26.73 | 19.72 | 35.62 | 4.61 | 23.30 | 459.2 | -.14 | -0 | -0 | -0 | -0 |
| 150 | 23.13 | 19.85 | 35.86 | 4.21 | 24.57 | 337.9 | .52 | -0 | -0 | -0 | -0 |
| 208 | 17.56 | 19.53 | 35.28 | 3.26 | 25.61 | 238.3 | 1.97 | -0 | -0 | -0 | -0 |
| 304 | 10.65 | 19.25 | 34.78 | .88 | 26.68 | 136.7 | 5.16 | -0 | -0 | -0 | -0 |
| 383 | 9.29 | 999.00g) | 999.00 | 999.00h) | 999.00 | 999.0 | 999.00 | -0 | -0 | -0 | -0 |
| 560 | 6.91 | 19.21 | 34.70 | 1.56 | 27.22 | 85.9 | 5.03 | -0 | -0 | -0 | -0 |

INTERPOLATED AND COMPUTED VALUES AT STANDARD DEPTHS

| Z (m) | T (°C) | Cl (‰) | S (‰) | $\sigma_T$ (gm/L) | $\delta_T$ (cl/T) | $\delta$ (cl/T) | $\Delta D_{Z/0}$ (dyn m) | $\Delta D_{Z/Z\,MAX}$ (dyn m) | $Q_Z$ (m-dynm) |
|---|---|---|---|---|---|---|---|---|---|
| 0 | 26.90 | 19.77 | 35.71 | 23.31 | 457.9 | 458.0 | 0 | 1.354 | 275.0 |
| 10 | 26.88 | 19.79 | 35.76 | 23.35 | 454.2 | 454.7 | .046 | 1.308 | 261.7 |
| 20 | 26.85 | 19.79 | 35.76 | 23.36 | 453.2 | 454.1 | .091 | 1.263 | 248.8 |
| 30 | 26.81 | 19.79 | 35.75 | 23.36 | 452.6 | 453.9 | .136 | 1.217 | 236.4 |
| 50 | 26.70 | 19.77 | 35.71 | 23.37 | 451.8 | 453.9 | .227 | 1.127 | 213.0 |
| 75 | 26.73 | 19.72 | 35.62 | 23.29 | 459.2 | 462.4 | .342 | 1.012 | 186.2 |
| 100 | 26.73 | 19.72 | 35.62 | 23.29 | 459.2 | 463.4 | .458 | .896 | 162.4 |
| 150 | 23.13 | 19.85 | 35.86 | 24.57 | 337.9 | 343.7 | .659 | .695 | 122.6 |
| 200 | 18.29 | 19.56 | 35.34 | 25.48 | 251.3 | 258.1 | .810 | .544 | 91.6 |
| 250 | 14.21 | 19.35 | 34.96 | 26.13 | 189.1 | 196.3 | .923 | .430 | 67.3 |
| 300 | 10.89 | 19.25 | 34.78 | 26.64 | 140.3 | 147.4 | 1.009 | .345 | 47.9 |
| 400 | 9.02 | 19.22 | 34.73 | 26.92 | 113.9 | 122.0 | 1.144 | .210 | 20.2 |
| 500 | 7.62 | 19.21 | 34.71 | 27.12 | 95.4 | 104.2 | 1.257 | .097 | 4.8 |
| 600 | 6.48 | 19.21 | 34.71 | 27.28 | 80.2 | 89.3 | 1.354 | 0 | 0 |

| STATION | DATE | TIME | LATITUDE | LONGITUDE | D |
|---|---|---|---|---|---|
| H 294 | FEB 14, 1964 | 1910-1957 | 10° 03.1'S | 134° 55.0'W | |

OBSERVED AND COMPUTED VALUES AT OBSERVED DEPTHS

| Z (m) | T (°C) | Cl (‰) | S (‰) | $O_2$ (ml/L) | $\sigma_T$ (gm/L) | $\delta_T$ (cl/L) | AOU (ml/L) | $PO_4$ —— (μg at./L) —— | $NO_3$ | $SiO_4$ | $NO_2$ |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 0 | 27.40 | 19.77 | 35.71 | 4.47 | 23.15 | 473.2 | -.05 | -0 | -0 | -0 | -0 |
| 48 | 27.38 | 19.77 | 35.71 | 4.49 | 23.15 | 472.6 | -.07 | -0 | -0 | -0 | -0 |
| 71 | 27.43 | 19.79 | 35.75 | 4.50 | 23.17 | 471.6 | -.08 | -0 | -0 | -0 | -0 |
| 95 | 27.22 | 19.95 | 36.04 | 4.44 | 23.45 | 444.3 | -.01 | -0 | -0 | -0 | -0 |
| 143 | 23.89 | 19.99 | 36.11 | 4.23 | 24.54 | 340.9 | .43 | -0 | -0 | -0 | -0 |
| 202 | 20.85 | 19.77 | 35.71 | 3.93 | 25.10 | 287.4 | .99 | -0 | -0 | -0 | -0 |
| 301 | 12.72 | 19.27 | 34.81 | 2.03 | 26.32 | 171.0 | 3.75 | -0 | -0 | -0 | -0 |
| 394 | 9.38 | 19.16 | 34.61 | 1.72 | 26.77 | 128.1 | 4.50 | -0 | -0 | -0 | -0 |
| 576 | 7.16 | 19.21 | 34.70 | 1.68 | 27.18 | 89.2 | 4.87 | -0 | -0 | -0 | -0 |

INTERPOLATED AND COMPUTED VALUES AT STANDARD DEPTHS

| Z (m) | T (°C) | Cl (‰) | S (‰) | $\sigma_T$ (gm/L) | $\delta_T$ (cl/T) | $\delta$ (cl/T) | $\Delta D_{Z/0}$ (dyn m) | $\Delta D_{Z/Z\,MAX}$ (dyn m) | $Q_Z$ (m-dynm) |
|---|---|---|---|---|---|---|---|---|---|
| 0 | 27.40 | 19.77 | 35.71 | 23.15 | 473.2 | 473.3 | 0 | 1.449 | 302.7 |
| 10 | 27.39 | 19.77 | 35.71 | 23.15 | 473.2 | 473.7 | .047 | 1.402 | 288.4 |
| 20 | 27.38 | 19.77 | 35.71 | 23.15 | 473.1 | 474.0 | .095 | 1.354 | 274.6 |
| 30 | 27.38 | 19.77 | 35.71 | 23.15 | 473.0 | 474.3 | .142 | 1.307 | 261.3 |
| 50 | 27.39 | 19.77 | 35.72 | 23.15 | 472.6 | 474.7 | .237 | 1.212 | 236.1 |
| 75 | 27.40 | 19.80 | 35.77 | 23.19 | 469.0 | 472.1 | .355 | 1.094 | 207.3 |
| 100 | 27.01 | 19.95 | 36.05 | 23.52 | 437.5 | 441.7 | .470 | .979 | 181.4 |
| 150 | 23.60 | 19.97 | 36.08 | 24.59 | 335.4 | 341.3 | .665 | .784 | 137.3 |
| 200 | 20.98 | 19.78 | 35.73 | 25.07 | 289.5 | 296.8 | .825 | .624 | 102.1 |
| 250 | 16.94 | 19.48 | 35.18 | 25.69 | 231.2 | 239.3 | .959 | .490 | 74.3 |
| 300 | 12.80 | 19.27 | 34.82 | 26.31 | 172.1 | 180.1 | 1.064 | .385 | 52.4 |
| 400 | 9.29 | 19.16 | 34.62 | 26.79 | 126.6 | 134.9 | 1.221 | .228 | 21.8 |
| 500 | 7.99 | 19.19 | 34.66 | 27.03 | 103.7 | 112.9 | 1.345 | .104 | 5.2 |
| 600 | 6.92 | 19.22 | 34.72 | 27.23 | 85.1 | 94.7 | 1.449 | 0 | 0 |

| STATION | DATE | TIME | LATITUDE | LONGITUDE | D |
|---|---|---|---|---|---|
| H 296 | FEB 15, 1964 | 2010-2122 | 09° 20.2′S | 135° 36.5′W | |

OBSERVED AND COMPUTED VALUES AT OBSERVED DEPTHS

| Z (m) | T (°C) | Cl (‰) | S (‰) | $O_2$ (ml/L) | $\sigma_T$ (gm/L) | $\delta_T$ (cl/L) | AOU (ml/L) | $PO_4$ (μg at./L) | $NO_3$ (μg at./L) | $SiO_4$ (μg at./L) | $NO_2$ (μg at./L) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 0 | 27.70 | 19.79 | 35.75 | 4.57 | 23.08 | 479.9 | -.17 | -0 | -0 | -0 | -0 |
| 49 | 27.46 | 19.77 | 35.71 | 4.67 | 23.13 | 475.1 | -.25 | -0 | -0 | -0 | -0 |
| 73 | 27.46 | 999.00 | 999.00 | 4.55 | 999.00 | 999.0 | 999.00 | -0 | -0 | -0 | -0 |
| 97 | 27.28 | 19.79 | 35.75 | 4.51 | 23.21 | 466.9 | -.08 | -0 | -0 | -0 | -0 |
| 146 | 22.89 | 19.79 | 35.75 | 4.05 | 24.55 | 339.1 | .70 | -0 | -0 | -0 | -0 |
| 200 | 18.82 | 19.63 | 35.46 | 3.75 | 25.44 | 255.0 | 1.36 | -0 | -0 | -0 | -0 |
| 329 | 13.99 | 19.21 | 34.70 | 1.04 | 25.98 | 203.6 | 4.59 | -0 | -0 | -0 | -0 |
| 414 | 9.27 | 19.25 | 34.78 | 1.38 | 26.92 | 114.4 | 4.85 | -0 | -0 | -0 | -0 |
| 585 | 7.33 | 999.00 | 999.00 | 1.25 | 999.00 | 999.0 | 999.00 | -0 | -0 | -0 | -0 |

INTERPOLATED AND COMPUTED VALUES AT STANDARD DEPTHS

H 296

| Z (m) | T (°C) | Cl (‰) | S (‰) | $\sigma_T$ (gm/L) | $\delta_T$ (cl/T) | $\delta$ (cl/T) | $\Delta D_{Z/0}$ (dyn m) | $\Delta D_{Z/Z\,MAX}$ (dyn m) | $Q_Z$ (m-dyn m) |
|---|---|---|---|---|---|---|---|---|---|
| 0 | 27.70 | 23.49 | 42.44 | 28.13 | 0 | .1 | 0 | | |
| 10 | 27.67 | 23.07 | 41.67 | 27.55 | 54.0 | 54.5 | .003 | | |
| 20 | 27.64 | 22.54 | 40.71 | 26.84 | 121.8 | 122.8 | .012 | | |
| 30 | 27.59 | 21.85 | 39.47 | 25.91 | 209.6 | 210.9 | .028 | | |
| 50 | 27.46 | 19.77 | 35.72 | 23.13 | 474.9 | 477.1 | .097 | | |
| 75 | 27.45 | 19.80 | 35.77 | 23.17 | 470.7 | 473.8 | .216 | | |
| 100 | 27.12 | 19.82 | 35.80 | 23.30 | 458.6 | 462.8 | .333 | | |
| 150 | 22.54 | 19.77 | 35.72 | 24.63 | 331.9 | 337.6 | .533 | | |
| 200 | 18.82 | 19.63 | 35.46 | 25.44 | 255.0 | 261.9 | .683 | | |
| 250 | 16.66 | 19.42 | 35.09 | 25.68 | 231.9 | 239.9 | .808 | | |
| 300 | 14.89 | 19.28 | 34.82 | 25.88 | 213.1 | 222.0 | .924 | | |
| 400 | 9.98 | 19.23 | 34.75 | 26.78 | 127.7 | 136.5 | 1.103 | | |
| 500 | 8.21 | | | | | | | | |
| 600 | 7.19 | | | | | | | | |

| STATION | DATE | TIME | LATITUDE | LONGITUDE | D |
|---|---|---|---|---|---|
| H 299 | FEB 16, 1964 | 0830-0935 | 07° 49.6′S | 136° 42.4′W | |

OBSERVED AND COMPUTED VALUES AT OBSERVED DEPTHS

| Z (m) | T (°C) | Cl (‰) | S (‰) | $O_2$ (ml/L) | $\sigma_T$ (gm/L) | $\delta_T$ (cl/L) | AOU (ml/L) | $PO_4$ (μg at./L) | $NO_3$ (μg at./L) | $SiO_4$ (μg at./L) | $NO_2$ (μg at./L) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 0 | 27.30 | 19.74 i) | 35.66 | 4.47 | 23.14 | 474.0 | -.04 | -0 | -0 | -0 | -0 |
| 50 | 27.32 | 999.00 | 999.00 | 4.69 | 999.00 | 999.0 | 999.00 | -0 | -0 | -0 | -0 |
| 75 | 27.33 | 19.74 | 35.66 | 4.66 | 23.13 | 475.0 | -.23 | -0 | -0 | -0 | -0 |
| 100 | 27.38 | 19.73 | 35.64 | 4.61 | 23.10 | 477.8 | -.18 | -0 | -0 | -0 | -0 |
| 149 | 23.99 | 19.91 | 35.97 | 4.19 | 24.40 | 354.2 | .47 | -0 | -0 | -0 | -0 |
| 208 | 19.36 | 999.00 | 999.00 | 3.88 | 999.00 | 999.0 | 999.00 | -0 | -0 | -0 | -0 |
| 299 | 10.69 | 19.23 | 34.74 | 1.30 | 26.65 | 140.1 | 4.74 | -0 | -0 | -0 | -0 |
| 391 | 8.88 | 19.18 | 34.65 | 1.43 | 26.88 | 117.8 | 4.86 | -0 | -0 | -0 | -0 |
| 590 | 6.63 | 19.19 j) | 34.67 | 2.18 | 27.23 | 85.0 | 4.46 | -0 | -0 | -0 | -0 |

H 299

INTERPOLATED AND COMPUTED VALUES AT STANDARD DEPTHS

| Z (m) | T (°C) | Cl (‰) | S (‰) | $\sigma_T$ (gm/L) | $\delta_T$ (cl/T) | $\delta$ (cl/T) | $\Delta D_{Z/0}$ (dyn m) | $\Delta D_{Z/Z\,MAX}$ (dyn m) | $Q_Z$ (m-dyn m) |
|---|---|---|---|---|---|---|---|---|---|
| 0 | 27.30 | 19.74 | 35.66 | 23.14 | 474.0 | 474.2 | 0 | 1.425 | 287.9 |
| 10 | 27.31 | 19.74 | 35.66 | 23.13 | 474.6 | 475.1 | .047 | 1.378 | 273.9 |
| 20 | 27.32 | 19.74 | 35.66 | 23.13 | 474.7 | 475.6 | .095 | 1.330 | 260.4 |
| 30 | 27.32 | 19.74 | 35.66 | 23.13 | 474.8 | 476.1 | .143 | 1.283 | 247.3 |
| 50 | 27.32 | 19.74 | 35.66 | 23.13 | 474.9 | 477.0 | .238 | 1.187 | 222.6 |
| 75 | 27.33 | 19.74 | 35.66 | 23.13 | 475.0 | 478.1 | .357 | 1.068 | 194.4 |
| 100 | 27.38 | 19.73 | 35.64 | 23.10 | 477.8 | 482.0 | .477 | .948 | 169.2 |
| 150 | 23.93 | 19.90 | 35.96 | 24.41 | 353.0 | 358.9 | .688 | .738 | 127.1 |
| 200 | 20.12 | 19.60 | 35.41 | 25.06 | 291.0 | 298.1 | .852 | .574 | 94.3 |
| 250 | 15.41 | 19.34 | 34.94 | 25.85 | 215.7 | 223.3 | .982 | .443 | 68.9 |
| 300 | 10.67 | 19.23 | 34.74 | 26.65 | 139.8 | 146.8 | 1.075 | .351 | 49.0 |
| 400 | 8.76 | 19.18 | 34.65 | 26.90 | 115.9 | 123.9 | 1.210 | .215 | 20.8 |
| 500 | 7.54 | 19.18 | 34.65 | 27.09 | 98.2 | 106.9 | 1.325 | .100 | 5.0 |
| 600 | 6.54 | 19.19 | 34.67 | 27.24 | 83.7 | 92.9 | 1.425 | 0 | 0 |

| STATION | DATE | TIME | LATITUDE | LONGITUDE | D |
|---|---|---|---|---|---|
| H 302 | FEB 16, 1964 | 2026-2105 | 06° 20.3'S | 137° 49.2'W | |

OBSERVED AND COMPUTED VALUES AT OBSERVED DEPTHS

| Z (m) | T (°C) | Cl (‰) | S (‰) | $O_2$ (ml/L) | $\sigma_T$ (gm/L) | $\delta_T$ (cl/L) | AOU (ml/L) | $PO_4$ (µg at./L) | $NO_3$ (µg at./L) | $SiO_4$ (µg at./L) | $NO_2$ (µg at./L) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 0 | 27.40 | 19.69 | 35.57 | 4.56 | 23.04 | 483.6 | -.13 | -0 | -0 | -0 | -0 |
| 50 | 27.16 | 19.67 | 35.53 | 4.47 | 23.09 | 478.8 | -.03 | -0 | -0 | -0 | -0 |
| 75 | 27.18 | 19.68 | 35.55 | 4.50 | 23.10 | 478.1 | -.06 | -0 | -0 | -0 | -0 |
| 100 | 27.23 | 19.68 | 35.55 | 4.48 | 23.08 | 479.7 | -.04 | -0 | -0 | -0 | -0 |
| 150 | 23.03 | 19.95 | 36.04 | 3.97 | 24.73 | 322.1 | .76 | -0 | -0 | -0 | -0 |
| 200 | 17.93 | 19.57 | 35.35 | 3.30 | 25.58 | 241.7 | 1.90 | -0 | -0 | -0 | -0 |
| 289 | 11.38 | 19.27 | 34.81 | .66 | 26.58 | 146.6 | 5.29 | -0 | -0 | -0 | -0 |
| 382 | 10.09 | 19.23 | 34.74 | .93 | 26.75 | 130.1 | 5.19 | -0 | -0 | -0 | -0 |
| 555 | 7.31 | 19.16 | 34.61 | 1.30 | 27.09 | 98.0 | 5.23 | -0 | -0 | -0 | -0 |

INTERPOLATED AND COMPUTED VALUES AT STANDARD DEPTHS

| Z (m) | T (°C) | Cl (‰) | S (‰) | $\sigma_T$ (gm/L) | $\delta_T$ (cl/T) | $\delta$ (cl/T) | $\Delta D_{Z/0}$ (dyn m) | $\Delta D_{Z/Z\,MAX}$ (dyn m) | $Q_Z$ (m-dyn m) |
|---|---|---|---|---|---|---|---|---|---|
| 0 | 27.40 | 19.69 | 35.57 | 23.04 | 483.6 | 483.7 | 0 | 1.402 | 289.2 |
| 10 | 27.37 | 19.69 | 35.57 | 23.04 | 483.1 | 483.6 | .048 | 1.354 | 275.5 |
| 20 | 27.34 | 19.68 | 35.56 | 23.05 | 482.4 | 483.3 | .097 | 1.305 | 262.2 |
| 30 | 27.30 | 19.68 | 35.55 | 23.06 | 481.6 | 482.9 | .145 | 1.257 | 249.3 |
| 50 | 27.16 | 19.67 | 35.53 | 23.09 | 478.8 | 481.0 | .241 | 1.161 | 225.2 |
| 75 | 27.18 | 19.68 | 35.55 | 23.10 | 478.1 | 481.3 | .362 | 1.040 | 197.7 |
| 100 | 27.23 | 19.68 | 35.55 | 23.08 | 479.7 | 483.9 | .482 | .920 | 173.1 |
| 150 | 23.03 | 19.95 | 36.04 | 24.73 | 322.1 | 327.9 | .685 | .717 | 132.2 |
| 200 | 17.93 | 19.57 | 35.35 | 25.58 | 241.7 | 248.4 | .829 | .573 | 100.0 |
| 250 | 13.96 | 19.35 | 34.96 | 26.18 | 184.1 | 191.2 | .939 | .463 | 74.1 |
| 300 | 11.21 | 19.26 | 34.80 | 26.60 | 144.4 | 151.7 | 1.025 | .377 | 53.1 |
| 400 | 9.75 | 19.22 | 34.72 | 26.79 | 126.1 | 134.8 | 1.168 | .234 | 22.5 |
| 500 | 8.09 | 19.17 | 34.64 | 27.00 | 106.9 | 116.2 | 1.294 | .108 | 5.4 |
| 600 | 6.73 | 19.15 | 34.60 | 27.16 | 91.3 | 100.7 | 1.402 | 0 | 0 |

| STATION | DATE | TIME | LATITUDE | LONGITUDE | D |
|---|---|---|---|---|---|
| H 305 | FEB 17, 1964 | 0835-0905 | 04° 48.5'S | 139° 00.0'W | 23 |

OBSERVED AND COMPUTED VALUES AT OBSERVED DEPTHS

| Z (m) | T (°C) | Cl (‰) | S (‰) | $O_2$ (ml/L) | $\sigma_T$ (gm/L) | $\delta_T$ (cl/L) | AOU (ml/L) | $PO_4$ (µg at./L) | $NO_3$ (µg at./L) | $SiO_4$ (µg at./L) | $NO_2$ (µg at./L) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 0 | 26.50 | 19.54 | 35.30 | 4.58 | 23.12 | 475.6 | -.08 | -0 | -0 | -0 | -0 |
| 50 | 26.35 | 19.51 | 35.25 | 4.57 | 23.13 | 475.0 | -.06 | -0 | -0 | -0 | -0 |
| 75 | 26.34 | 19.51 | 35.25 | 4.58 | 23.13 | 474.7 | -.07 | -0 | -0 | -0 | -0 |
| 100 | 26.24 | 19.56 | 35.34 | 4.52 | 23.23 | 465.2 | -.01 | -0 | -0 | -0 | -0 |
| 149 | 19.57 | 19.69 | 35.57 | 3.58 | 25.33 | 265.5 | 1.46 | -0 | -0 | -0 | -0 |
| 202 | 13.10 | 19.32 | 34.90 | .54 | 26.32 | 171.6 | 5.19 | -0 | -0 | -0 | -0 |
| 298 | 11.55 | 19.27 | 34.81 | 1.43 | 26.55 | 149.6 | 4.49 | -0 | -0 | -0 | -0 |
| 388 | 9.88 | 19.22 | 34.72 | .71 | 26.78 | 128.0 | 5.44 | -0 | -0 | -0 | -0 |
| 571 | 7.52 | 19.17 | 34.63 | 1.13 | 27.08 | 99.5 | 5.37 | -0 | -0 | -0 | -0 |

INTERPOLATED AND COMPUTED VALUES AT STANDARD DEPTHS

| Z (m) | T (°C) | Cl (‰) | S (‰) | $\sigma_T$ (gm/L) | $\delta_T$ (cl/T) | $\delta$ (cl/T) | $\Delta D_{Z/0}$ (dyn m) | $\Delta D_{Z/Z\,MAX}$ (dyn m) | $Q_Z$ (m-dynm) |
|---|---|---|---|---|---|---|---|---|---|
| 0 | 26.50 | 19.54 | 35.30 | 23.12 | 475.6 | 475.7 | 0 | 1.324 | 277.8 |
| 10 | 26.48 | 19.54 | 35.29 | 23.12 | 475.5 | 476.1 | .048 | 1.277 | 264.8 |
| 20 | 26.46 | 19.53 | 35.29 | 23.12 | 475.5 | 476.4 | .095 | 1.229 | 252.2 |
| 30 | 26.44 | 19.53 | 35.28 | 23.13 | 475.3 | 476.7 | .143 | 1.181 | 240.2 |
| 50 | 26.35 | 19.51 | 35.25 | 23.13 | 475.0 | 477.1 | .238 | 1.086 | 217.5 |
| 75 | 26.34 | 19.51 | 35.25 | 23.13 | 474.7 | 477.8 | .358 | .967 | 191.8 |
| 100 | 26.24 | 19.56 | 35.34 | 23.23 | 465.2 | 469.3 | .476 | .848 | 169.2 |
| 150 | 19.43 | 19.68 | 35.55 | 25.35 | 263.4 | 268.7 | .661 | .664 | 131.4 |
| 200 | 13.31 | 19.33 | 34.92 | 26.28 | 174.7 | 180.2 | .773 | .552 | 101.0 |
| 250 | 12.25 | 19.29 | 34.85 | 26.44 | 159.6 | 166.1 | .859 | .465 | 75.6 |
| 300 | 11.51 | 19.27 | 34.81 | 26.55 | 149.1 | 156.5 | .940 | .384 | 54.3 |
| 400 | 9.69 | 19.21 | 34.71 | 26.80 | 125.8 | 134.4 | 1.085 | .239 | 23.2 |
| 500 | 8.33 | 19.18 | 34.65 | 26.97 | 109.3 | 118.8 | 1.212 | .112 | 5.6 |
| 600 | 7.22 | 19.17 | 34.63 | 27.11 | 95.8 | 105.9 | 1.324 | 0 | 0 |

| STATION | DATE | TIME | LATITUDE | LONGITUDE | D |
|---|---|---|---|---|---|
| H 307 | FEB 17, 1964 | 2025-2106 | 03° 09.7'S | 140° 12.0'W | |

OBSERVED AND COMPUTED VALUES AT OBSERVED DEPTHS

| Z (m) | T (°C) | Cl (‰) | S (‰) | $O_2$ (ml/L) | $\sigma_T$ (gm/L) | $\delta_T$ (cl/L) | AOU (ml/L) | $PO_4$ (μg at./L) | $NO_3$ (μg at./L) | $SiO_4$ (μg at./L) | $NO_2$ (μg at./L) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 0 | 27.00 | 19.65 | 35.50 | 4.52 | 23.11 | 476.5 | -.06 | -0 | -0 | -0 | -0 |
| 49 | 26.75 | 19.64 | 35.48 | 4.56 | 23.18 | 470.2 | -.09 | -0 | -0 | -0 | -0 |
| 73 | 26.65 | 19.64 | 35.48 | 4.54 | 23.21 | 467.2 | -.06 | -0 | -0 | -0 | -0 |
| 97 | 25.21 | 19.57 | 35.35 | 4.42 | 23.57 | 433.4 | .17 | -0 | -0 | -0 | -0 |
| 146 | 13.52 | 19.37 | 34.99 | .75 | 26.30 | 173.1 | 4.93 | -0 | -0 | -0 | -0 |
| 202 | 12.72 | 19.34 | 34.94 | .55 | 26.42 | 161.7 | 5.22 | -0 | -0 | -0 | -0 |
| 290 | 11.87 | 19.30 | 34.87 | .66 | 26.53 | 151.4 | 5.22 | -0 | -0 | -0 | -0 |
| 378 | 9.90 | 19.23 | 34.74 | .43 | 26.79 | 127.0 | 5.72 | -0 | -0 | -0 | -0 |
| 549 | 7.12 | 19.17 | 34.63 | 1.30 | 27.13 | 94.1 | 5.26 | -0 | -0 | -0 | -0 |

H 307

INTERPOLATED AND COMPUTED VALUES AT STANDARD DEPTHS

| Z (m) | T (°C) | Cl (‰) | S (‰) | $\sigma_T$ (gm/L) | $\delta_T$ (cl/T) | $\delta$ (cl/T) | $\Delta D_{Z/0}$ (dyn m) | $\Delta D_{Z/Z\,MAX}$ (dyn m) | $Q_Z$ (m-dyn m) |
|---|---|---|---|---|---|---|---|---|---|
| 0 | 27.00 | 19.65 | 35.50 | 23.11 | 476.5 | 476.6 | 0 | 1.233 | 258.7 |
| 10 | 26.97 | 19.65 | 35.50 | 23.12 | 475.8 | 476.3 | .048 | 1.185 | 246.6 |
| 20 | 26.94 | 19.65 | 35.49 | 23.13 | 474.9 | 475.8 | .095 | 1.138 | 235.0 |
| 30 | 26.89 | 19.65 | 35.49 | 23.14 | 473.7 | 475.1 | .143 | 1.090 | 223.8 |
| 50 | 26.75 | 19.64 | 35.48 | 23.18 | 470.1 | 472.2 | .238 | .996 | 203.0 |
| 75 | 26.58 | 19.64 | 35.47 | 23.23 | 465.4 | 468.5 | .355 | .878 | 179.6 |
| 100 | 24.75 | 19.55 | 35.31 | 23.67 | 423.0 | 427.0 | .467 | .766 | 159.0 |
| 150 | 13.45 | 19.37 | 34.99 | 26.31 | 172.2 | 176.4 | .618 | .615 | 124.5 |
| 200 | 12.74 | 19.34 | 34.94 | 26.41 | 162.1 | 167.5 | .704 | .529 | 95.9 |
| 250 | 12.22 | 19.32 | 34.89 | 26.48 | 155.6 | 162.1 | .786 | .447 | 71.5 |
| 300 | 11.62 | 19.29 | 34.85 | 26.56 | 148.2 | 155.7 | .866 | .367 | 51.1 |
| 400 | 9.48 | 19.22 | 34.72 | 26.84 | 122.0 | 130.5 | 1.009 | .224 | 21.5 |
| 500 | 7.82 | 19.18 | 34.65 | 27.04 | 102.3 | 111.3 | 1.130 | .103 | 5.2 |
| 600 | 6.46 | 19.16 | 34.62 | 27.21 | 86.2 | 95.4 | 1.233 | 0 | 0 |

| STATION | DATE | TIME | LATITUDE | LONGITUDE | D |
|---|---|---|---|---|---|
| H 310 | FEB 18, 1964 | 0825-0904 | 01° 32.1'S | 141° 22.1'W | 25 |

OBSERVED AND COMPUTED VALUES AT OBSERVED DEPTHS

| Z (m) | T (°C) | Cl (‰) | S (‰) | $O_2$ (ml/L) | $\sigma_T$ (gm/L) | $\delta_T$ (cl/L) | AOU (ml/L) | $PO_4$ (μg at./L) | $NO_3$ (μg at./L) | $SiO_4$ (μg at./L) | $NO_2$ (μg at./L) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 0 | 26.40 | 19.46 | 35.16 | 4.57 | 23.05 | 483.0 | -.06 | -0 | -0 | -0 | -0 |
| 50 | 26.21 | 19.47 | 35.17 | 4.63 | 23.12 | 476.0 | -.11 | -0 | -0 | -0 | -0 |
| 75 | 25.50 | 19.49 | 35.21 | 4.46 | 23.37 | 452.3 | .11 | -0 | -0 | -0 | -0 |
| 100 | 21.08 | 19.66 | 35.52 | 3.49 | 24.88 | 307.7 | 1.42 | -0 | -0 | -0 | -0 |
| 149 | 13.00 | 19.33 | 34.92 | 1.14 | 26.35 | 168.4 | 4.60 | -0 | -0 | -0 | -0 |
| 204 | 12.27 | 19.31 | 34.88 | .69 | 26.47 | 157.3 | 5.14 | -0 | -0 | -0 | -0 |
| 282 | 11.30 | 19.28 | 34.83 | .88 | 26.61 | 143.9 | 5.08 | -0 | -0 | -0 | -0 |
| 375 | 9.55 | 19.21 | 34.70 | .97 | 26.82 | 124.1 | 5.23 | -0 | -0 | -0 | -0 |
| 556 | 6.85 | 19.18 | 34.65 | 1.37 | 27.18 | 89.2 | 5.23 | -0 | -0 | -0 | -0 |

H 310

INTERPOLATED AND COMPUTED VALUES AT STANDARD DEPTHS

| Z (m) | T (°C) | Cl (‰) | S (‰) | $\sigma_T$ (gm/L) | $\delta_T$ (cl/T) | $\delta$ (cl/T) | $\Delta D_{Z/0}$ (dyn m) | $\Delta D_{Z/Z\,MAX}$ (dyn m) | $Q_Z$ (m-dyn m) |
|---|---|---|---|---|---|---|---|---|---|
| 0 | 26.40 | 19.46 | 35.15 | 23.05 | 483.0 | 483.1 | 0 | 1.166 | 245.3 |
| 10 | 26.38 | 19.46 | 35.16 | 23.05 | 482.2 | 482.7 | .048 | 1.118 | 233.8 |
| 20 | 26.35 | 19.46 | 35.16 | 23.06 | 481.2 | 482.2 | .097 | 1.070 | 222.9 |
| 30 | 26.32 | 19.46 | 35.16 | 23.08 | 480.0 | 481.3 | .145 | 1.021 | 212.5 |
| 50 | 26.21 | 19.47 | 35.17 | 23.12 | 476.0 | 478.1 | .241 | .925 | 193.0 |
| 75 | 25.50 | 19.49 | 35.21 | 23.37 | 452.3 | 455.4 | .357 | .809 | 171.3 |
| 100 | 21.08 | 19.66 | 35.52 | 24.88 | 307.7 | 311.5 | .453 | .713 | 152.3 |
| 150 | 12.98 | 19.33 | 34.92 | 26.35 | 168.1 | 172.3 | .574 | .592 | 119.7 |
| 200 | 12.32 | 19.31 | 34.89 | 26.46 | 158.0 | 163.3 | .658 | .508 | 92.2 |
| 250 | 11.66 | 19.29 | 34.85 | 26.55 | 148.9 | 155.2 | .738 | .428 | 68.8 |
| 300 | 10.92 | 19.26 | 34.80 | 26.65 | 139.6 | 146.7 | .813 | .353 | 49.2 |
| 400 | 9.11 | 19.20 | 34.69 | 26.88 | 118.4 | 126.6 | .950 | .216 | 20.8 |
| 500 | 7.58 | 19.18 | 34.65 | 27.08 | 98.6 | 107.4 | 1.067 | .099 | 5.0 |
| 600 | 6.33 | 19.18 | 34.65 | 27.25 | 82.4 | 91.4 | 1.166 | 0 | 0 |

| STATION | DATE | TIME | LATITUDE | LONGITUDE | D |
|---|---|---|---|---|---|
| H 313 | FEB 18, 1964 | 2025-2107 | 00° 06.8'N | 142° 34.6'W | |

OBSERVED AND COMPUTED VALUES AT OBSERVED DEPTHS

| Z | T | Cl | S | $O_2$ | $\sigma_T$ | $\delta_T$ | AOU | $PO_4$ | $NO_3$ | $SiO_4$ | $NO_2$ |
|---|---|---|---|---|---|---|---|---|---|---|---|
| (m) | (°C) | (‰) | (‰) | (ml/L) | (gm/L) | (cl/L) | (ml/L) | (μg at./L) | | | |
| 0 | 26.30 | 19.47 | 35.17 | 4.17 | 23.09 | 478.7 | .35 | -0 | -0 | -0 | -0 |
| 48 | 25.76 | 19.50 | 35.23 | 4.11 | 23.30 | 458.7 | .44 | -0 | -0 | -0 | -0 |
| 71 | 25.39 | 19.60 | 35.41 | 3.88 | 23.55 | 434.8 | .69 | -0 | -0 | -0 | -0 |
| 95 | 22.32 | 19.64 | 35.48 | 3.09 | 24.51 | 343.2 | 1.72 | -0 | -0 | -0 | -0 |
| 143 | 14.99 | 19.48 | 35.19 | 2.84 | 26.14 | 188.3 | 2.66 | -0 | -0 | -0 | -0 |
| 225 | 12.33 | 19.40 | 35.05 | 1.94 | 26.58 | 146.5 | 3.88 | -0 | -0 | -0 | -0 |
| 247 | 11.91 | 19.40 | 35.05 | 2.06 | 26.66 | 138.8 | 3.81 | -0 | -0 | -0 | -0 |
| 270 | 11.17 | 19.35 | 34.96 | .89 | 26.73 | 132.3 | 5.08 | -0 | -0 | -0 | -0 |
| 491 | 7.75 | 19.24 | 34.76 | 1.00 | 27.14 | 93.3 | 5.46 | -0 | -0 | -0 | -0 |

INTERPOLATED AND COMPUTED VALUES AT STANDARD DEPTHS

| Z | T | Cl | S | $\sigma_T$ | $\delta_T$ | $\delta$ | $\Delta D_{Z/0}$ | $\Delta D_{Z/Z\,MAX}$ | $Q_Z$ |
|---|---|---|---|---|---|---|---|---|---|
| (m) | (°C) | (‰) | (‰) | (gm/L) | (cl/T) | (cl/T) | (dyn m) | (dyn m) | (m-dynm) |
| 0 | 26.30 | 19.47 | 35.17 | 23.09 | 478.7 | 478.8 | 0 | 1.037 | 180.8 |
| 10 | 26.24 | 19.47 | 35.18 | 23.11 | 476.4 | 476.9 | .048 | .989 | 170.7 |
| 20 | 26.16 | 19.48 | 35.19 | 23.15 | 473.4 | 474.3 | .095 | .942 | 161.0 |
| 30 | 26.05 | 19.48 | 35.20 | 23.19 | 469.6 | 470.9 | .143 | .894 | 151.9 |
| 50 | 25.73 | 19.51 | 35.24 | 23.32 | 457.1 | 459.3 | .236 | .801 | 134.9 |
| 75 | 25.05 | 19.61 | 35.42 | 23.66 | 424.1 | 427.2 | .346 | .691 | 116.3 |
| 100 | 21.71 | 19.62 | 35.44 | 24.65 | 329.5 | 333.3 | .441 | .596 | 100.2 |
| 150 | 14.71 | 19.47 | 35.17 | 26.18 | 183.9 | 188.4 | .572 | .465 | 73.7 |
| 200 | 13.02 | 19.42 | 35.08 | 26.46 | 157.4 | 162.8 | .660 | .377 | 52.6 |
| 250 | 11.81 | 19.39 | 35.03 | 26.67 | 137.9 | 144.3 | .736 | .301 | 35.7 |
| 300 | 10.57 | 19.32 | 34.91 | 26.80 | 125.4 | 132.4 | .806 | .231 | 22.4 |
| 400 | 8.92 | 19.27 | 34.81 | 27.00 | 106.7 | 114.7 | .929 | .108 | 5.4 |
| 500 | 7.65 | 19.24 | 34.75 | 27.15 | 92.1 | 100.9 | 1.037 | 0 | 0 |

| STATION | DATE | TIME | LATITUDE | LONGITUDE | D |
|---|---|---|---|---|---|
| H 316 | FEB 19, 1964 | 0825-0904 | 01° 41.8'N | 143° 48.0'W | 24 |

OBSERVED AND COMPUTED VALUES AT OBSERVED DEPTHS

| Z | T | Cl | S | $O_2$ | $\sigma_T$ | $\delta_T$ | AOU | $PO_4$ | $NO_3$ | $SiO_4$ | $NO_2$ |
|---|---|---|---|---|---|---|---|---|---|---|---|
| (m) | (°C) | (‰) | (‰) | (ml/L) | (gm/L) | (cl/L) | (ml/L) | (μg at./L) | | | |
| 0 | 26.70 | 19.40 | 35.05 | 4.15 | 22.87 | 499.8 | .34 | -0 | -0 | -0 | -0 |
| 50 | 26.38 | 19.40 | 35.05 | 4.16 | 22.97 | 490.2 | .35 | -0 | -0 | -0 | -0 |
| 75 | 26.31 | 19.43 | 35.10 | 4.09 | 23.03 | 484.2 | .43 | -0 | -0 | -0 | -0 |
| 100 | 25.84 | 19.42 | 35.08 | 4.10 | 23.17 | 471.5 | .45 | -0 | -0 | -0 | -0 |
| 150 | 13.12 | 19.32 | 34.90 | 1.39 | 26.31 | 172.0 | 4.34 | -0 | -0 | -0 | -0 |
| 208 | 11.97 | 19.28 | 34.83 | .85 | 26.48 | 155.8 | 5.02 | -0 | -0 | -0 | -0 |
| 304 | 11.18 | 19.26 | 34.79 | .95 | 26.60 | 144.5 | 5.02 | -0 | -0 | -0 | -0 |
| 387 | 9.62 | 19.25 | 34.78 | .78 | 26.86 | 119.9 | 5.40 | -0 | -0 | -0 | -0 |
| 522 | 6.99 | 19.17 | 34.63 | 1.01 | 27.15 | 92.4 | 5.57 | -0 | -0 | -0 | -0 |

INTERPOLATED AND COMPUTED VALUES AT STANDARD DEPTHS

| Z | T | Cl | S | $\sigma_T$ | $\delta_T$ | $\delta$ | $\Delta D_{Z/0}$ | $\Delta D_{Z/Z\,MAX}$ | $Q_Z$ |
|---|---|---|---|---|---|---|---|---|---|
| (m) | (°C) | (‰) | (‰) | (gm/L) | (cl/T) | (cl/T) | (dyn m) | (dyn m) | (m-dynm) |
| 0 | 26.70 | 19.40 | 35.05 | 22.87 | 499.8 | 500.0 | 0 | 1.150 | 199.1 |
| 10 | 26.66 | 19.40 | 35.05 | 22.88 | 498.8 | 499.3 | .050 | 1.100 | 187.8 |
| 20 | 26.62 | 19.40 | 35.05 | 22.89 | 497.4 | 498.3 | .100 | 1.050 | 177.1 |
| 30 | 26.56 | 19.40 | 35.05 | 22.91 | 495.7 | 497.0 | .150 | 1.000 | 166.8 |
| 50 | 26.38 | 19.40 | 35.05 | 22.97 | 490.2 | 492.3 | .249 | .901 | 147.8 |
| 75 | 26.31 | 19.43 | 35.10 | 23.03 | 484.2 | 487.3 | .371 | .779 | 126.8 |
| 100 | 25.84 | 19.42 | 35.08 | 23.17 | 471.5 | 475.6 | .491 | .658 | 108.8 |
| 150 | 13.12 | 19.32 | 34.90 | 26.31 | 172.0 | 176.1 | .654 | .496 | 80.0 |
| 200 | 12.11 | 19.28 | 34.84 | 26.46 | 157.8 | 163.0 | .739 | .411 | 57.3 |
| 250 | 11.59 | 19.27 | 34.81 | 26.54 | 150.3 | 156.6 | .819 | .331 | 38.8 |
| 300 | 11.21 | 19.26 | 34.79 | 26.60 | 144.9 | 152.1 | .896 | .254 | 24.2 |
| 400 | 9.33 | 19.24 | 34.76 | 26.89 | 116.8 | 125.2 | 1.035 | .115 | 5.8 |
| 500 | 7.37 | 19.18 | 34.65 | 27.11 | 96.3 | 104.9 | 1.150 | 0 | 0 |

| STATION | DATE | TIME | LATITUDE | LONGITUDE | D |
|---|---|---|---|---|---|
| H 319 | FEB 19, 1964 | 2025-2104 | 03° 22.8'N | 144° 58.2'W | |

OBSERVED AND COMPUTED VALUES AT OBSERVED DEPTHS

| Z (m) | T (°C) | Cl (‰) | S (‰) | $O_2$ (ml/L) | $\sigma_T$ (gm/L) | $\delta_T$ (cl/L) | AOU (ml/L) | $PO_4$ (µg at./L) | $NO_3$ (µg at./L) | $SiO_4$ (µg at./L) | $NO_2$ (µg at./L) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 0 | 27.30 | 19.32 | 34.90 | 4.38 | 22.57 | 528.5 | .07 | -0 | -0 | -0 | -0 |
| 50 | 27.11 | 19.31 | 34.88 | 4.44 | 22.62 | 524.0 | .03 | -0 | -0 | -0 | -0 |
| 75 | 27.12 | 19.31 | 34.88 | 4.16 | 22.61 | 524.3 | .31 | -0 | -0 | -0 | -0 |
| 100 | 26.49 | 19.39 | 35.03 | 3.70 | 22.92 | 494.8 | .81 | -0 | -0 | -0 | -0 |
| 150 | 15.34 | 19.21 | 34.70 | 2.23 | 25.69 | 231.3 | 3.25 | -0 | -0 | -0 | -0 |
| 214 | 11.01 | 19.18 | 34.65 | 2.32 | 26.52 | 152.2 | 3.68 | -0 | -0 | -0 | -0 |
| 274 | 10.45 | 19.21 | 34.70 | 1.63 | 26.66 | 138.7 | 4.44 | -0 | -0 | -0 | -0 |
| 398 | 9.09 | 19.18 | 34.65 | 1.40 | 26.85 | 120.9 | 4.86 | -0 | -0 | -0 | -0 |
| 570 | 6.71 | 19.14 | 34.58 | 1.20 | 27.15 | 92.8 | 5.43 | -0 | -0 | -0 | -0 |

INTERPOLATED AND COMPUTED VALUES AT STANDARD DEPTHS

| Z (m) | T (°C) | Cl (‰) | S (‰) | $\sigma_T$ (gm/L) | $\delta_T$ (cl/T) | $\delta$ (cl/T) | $\Delta D_{Z/0}$ (dyn m) | $\Delta D_{Z/Z\,MAX}$ (dyn m) | $Q_Z$ (m-dynm) |
|---|---|---|---|---|---|---|---|---|---|
| 0 | 27.30 | 19.32 | 34.90 | 22.57 | 528.5 | 528.7 | 0 | 1.323 | 263.9 |
| 10 | 27.28 | 19.32 | 34.90 | 22.57 | 528.0 | 528.6 | .053 | 1.270 | 251.0 |
| 20 | 27.25 | 19.32 | 34.90 | 22.58 | 527.4 | 528.3 | .106 | 1.217 | 238.5 |
| 30 | 27.22 | 19.32 | 34.89 | 22.59 | 526.6 | 527.9 | .159 | 1.164 | 226.6 |
| 50 | 27.11 | 19.31 | 34.88 | 22.62 | 524.0 | 526.2 | .264 | 1.059 | 204.4 |
| 75 | 27.12 | 19.31 | 34.88 | 22.61 | 524.3 | 527.5 | .396 | .927 | 179.6 |
| 100 | 26.49 | 19.39 | 35.03 | 22.92 | 494.8 | 498.9 | .524 | .799 | 158.0 |
| 150 | 15.34 | 19.21 | 34.70 | 25.69 | 231.3 | 235.9 | .708 | .615 | 122.6 |
| 200 | 11.84 | 19.18 | 34.64 | 26.36 | 167.2 | 172.4 | .810 | .513 | 94.4 |
| 250 | 10.66 | 19.20 | 34.68 | 26.61 | 143.7 | 149.6 | .890 | .433 | 70.8 |
| 300 | 10.12 | 19.20 | 34.69 | 26.71 | 134.4 | 141.1 | .963 | .360 | 51.0 |
| 400 | 9.06 | 19.18 | 34.65 | 26.85 | 120.6 | 128.7 | 1.098 | .225 | 21.7 |
| 500 | 7.58 | 19.15 | 34.59 | 27.04 | 103.0 | 111.8 | 1.218 | .105 | 5.2 |
| 600 | 6.37 | 19.14 | 34.57 | 27.19 | 88.7 | 97.7 | 1.323 | 0 | 0 |

H 319

| STATION | DATE | TIME | LATITUDE | LONGITUDE | D |
|---|---|---|---|---|---|
| H 322 | FEB 20, 1964 | 0825-0904 | 05° 02.1'N | 145° 59.0'W | 23 |

OBSERVED AND COMPUTED VALUES AT OBSERVED DEPTHS

| Z (m) | T (°C) | Cl (‰) | S (‰) | $O_2$ (ml/L) | $\sigma_T$ (gm/L) | $\delta_T$ (cl/L) | AOU (ml/L) | $PO_4$ (µg at./L) | $NO_3$ (µg at./L) | $SiO_4$ (µg at./L) | $NO_2$ (µg at./L) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 0 | 27.30 | 19.41 | 35.07 | 4.13 | 22.69 | 516.9 | .32 | -0 | -0 | -0 | -0 |
| 49 | 27.14 | 19.34 | 34.94 | 4.17 | 22.65 | 521.0 | .29 | -0 | -0 | -0 | -0 |
| 74 | 27.19 | 19.33 | 34.92 | 4.14 | 22.62 | 523.9 | .32 | -0 | -0 | -0 | -0 |
| 99 | 27.17 | 19.33 | 34.92 | 4.04 | 22.63 | 523.3 | .42 | -0 | -0 | -0 | -0 |
| 148 | 18.29 | 19.23 | 34.74 | 2.84 | 25.02 | 294.7 | 2.34 | -0 | -0 | -0 | -0 |
| 208 | 10.62 | 19.17 | 34.63 | 1.38 | 26.58 | 146.9 | 4.67 | -0 | -0 | -0 | -0 |
| 307 | 9.36 | 19.18 | 34.65 | 1.38 | 26.81 | 125.1 | 4.85 | -0 | -0 | -0 | -0 |
| 408 | 8.53 | 19.18 | 34.65 | 1.14 | 26.94 | 112.5 | 5.21 | -0 | -0 | -0 | -0 |
| 586 | 6.86 | 19.12 | 34.54 | .70 | 27.10 | 97.4 | 5.91 | -0 | -0 | -0 | -0 |

H 322

INTERPOLATED AND COMPUTED VALUES AT STANDARD DEPTHS

| Z (m) | T (°C) | Cl (‰) | S (‰) | $\sigma_T$ (gm/L) | $\delta_T$ (cl/T) | $\delta$ (cl/T) | $\Delta D_{Z/0}$ (dyn m) | $\Delta D_{Z/Z\,MAX}$ (dyn m) | $Q_Z$ (m-dynm) |
|---|---|---|---|---|---|---|---|---|---|
| 0 | 27.30 | 19.41 | 35.06 | 22.69 | 516.9 | 517.0 | 0 | 1.344 | 265.7 |
| 10 | 27.28 | 19.39 | 35.02 | 22.66 | 519.4 | 519.9 | .052 | 1.292 | 252.5 |
| 20 | 27.26 | 19.38 | 35.00 | 22.66 | 520.1 | 521.0 | .104 | 1.240 | 239.9 |
| 30 | 27.23 | 19.36 | 34.98 | 22.65 | 520.5 | 521.9 | .156 | 1.188 | 227.7 |
| 50 | 27.14 | 19.34 | 34.94 | 22.65 | 521.2 | 523.3 | .261 | 1.083 | 205.0 |
| 75 | 27.19 | 19.33 | 34.92 | 22.62 | 523.8 | 527.0 | .392 | .952 | 179.6 |
| 100 | 27.07 | 19.33 | 34.91 | 22.65 | 520.8 | 525.0 | .523 | .820 | 157.5 |
| 150 | 17.99 | 19.22 | 34.72 | 25.08 | 288.9 | 294.0 | .728 | .616 | 121.6 |
| 200 | 11.50 | 19.16 | 34.61 | 26.40 | 163.9 | 168.9 | .844 | .500 | 93.7 |
| 250 | 10.02 | 19.17 | 34.64 | 26.68 | 136.6 | 142.2 | .922 | .422 | 70.6 |
| 300 | 9.43 | 19.18 | 34.65 | 26.79 | 126.4 | 132.8 | .990 | .353 | 51.2 |
| 400 | 8.59 | 19.18 | 34.65 | 26.93 | 113.4 | 121.2 | 1.117 | .226 | 22.2 |
| 500 | 7.59 | 19.14 | 34.58 | 27.03 | 104.0 | 112.8 | 1.234 | .109 | 5.5 |
| 600 | 6.75 | 19.12 | 34.54 | 27.11 | 96.4 | 105.9 | 1.344 | 0 | 0 |

| STATION | DATE | TIME | LATITUDE | LONGITUDE | D |
|---|---|---|---|---|---|
| H 325 | FEB 20, 1964 | 2025-2114 | 06° 43.0'N | 146° 49.2'W | |

OBSERVED AND COMPUTED VALUES AT OBSERVED DEPTHS

| Z | T | Cl | S | $O_2$ | $\sigma_T$ | $\delta_T$ | AOU | $PO_4$ | $NO_3$ | $SiO_4$ | $NO_2$ |
|---|---|---|---|---|---|---|---|---|---|---|---|
| (m) | (°C) | (‰) | (‰) | (ml/L) | (gm/L) | (cl/L) | (ml/L) | —— (μg at./L) —— | | | |
| 0 | 27.50 | 19.26 | 34.79 | 4.20 | 22.42 | 542.5 | .24 | -0 | -0 | -0 | -0 |
| 83 | 21.77 | 19.25 | 34.78 | 3.71 | 24.13 | 379.3 | 1.16 | -0 | -0 | -0 | -0 |
| 104 | 16.31 | 19.18 | 34.65 | 2.79 | 25.43 | 256.1 | 2.59 | -0 | -0 | -0 | -0 |
| 124 | 13.50 | 19.15 | 34.60 | 1.65 | 26.00 | 201.8 | 4.04 | -0 | -0 | -0 | -0 |
| 166 | 11.20 | 19.21 | 34.70 | 2.64 | 26.53 | 151.5 | 3.33 | -0 | -0 | -0 | -0 |
| 229 | 10.89 | 19.21 | 34.70 | .41 | 26.58 | 146.1 | 5.60 | -0 | -0 | -0 | -0 |
| 247 | 10.14 | 19.22 | 34.72 | .58 | 26.73 | 132.2 | 5.53 | -0 | -0 | -0 | -0 |
| 379 | 8.79 | 19.19 k) | 34.67 | .85 | 26.91 | 115.1 | 5.46 | -0 | -0 | -0 | -0 |

INTERPOLATED AND COMPUTED VALUES AT STANDARD DEPTHS

| Z | T | Cl | S | $\sigma_T$ | $\delta_T$ | $\delta$ | $\Delta D_{Z/0}$ | $\Delta D_{Z/Z\,MAX}$ | $Q_Z$ |
|---|---|---|---|---|---|---|---|---|---|
| (m) | (°C) | (‰) | (‰) | (gm/L) | (cl/T) | (cl/T) | (dyn m) | (dyn m) | (m-dynm) |
| 0 | 27.50 | 19.26 | 34.79 | 22.42 | 542.5 | 542.6 | 0 | .914 | 128.1 |
| 10 | 27.13 | 19.25 | 34.78 | 22.53 | 532.0 | 532.6 | .054 | .860 | 119.2 |
| 20 | 26.72 | 19.25 | 34.77 | 22.66 | 520.1 | 521.1 | .106 | .808 | 110.9 |
| 30 | 26.24 | 19.24 | 34.76 | 22.80 | 506.5 | 507.8 | .158 | .756 | 103.0 |
| 50 | 25.03 | 19.23 | 34.74 | 23.16 | 472.2 | 474.3 | .256 | .658 | 88.9 |
| 75 | 22.78 | 19.24 | 34.75 | 23.83 | 408.0 | 411.0 | .367 | .547 | 73.8 |
| 100 | 17.32 | 19.18 | 34.65 | 25.19 | 278.9 | 282.2 | .453 | .461 | 61.2 |
| 150 | 12.00 | 19.18 | 34.66 | 26.34 | 169.0 | 172.9 | .567 | .347 | 41.0 |
| 200 | 11.02 | 19.21 | 34.70 | 26.56 | 148.4 | 153.2 | .649 | .266 | 25.7 |
| 250 | 10.10 | 19.22 | 34.72 | 26.73 | 131.8 | 137.4 | .721 | .193 | 14.3 |
| 300 | 9.53 | 19.20 | 34.69 | 26.81 | 124.4 | 130.9 | .788 | .126 | 6.3 |
| 400 | 8.62 | 19.19 | 34.66 | 26.93 | 112.9 | 120.7 | .914 | 0 | 0 |

| STATION | DATE | TIME | LATITUDE | LONGITUDE | D |
|---|---|---|---|---|---|
| H 331 | FEB 21, 1964 | 2025-2104 | 09° 40.5'N | 148° 58.0'W | |

OBSERVED AND COMPUTED VALUES AT OBSERVED DEPTHS

| Z | T | Cl | S | $O_2$ | $\sigma_T$ | $\delta_T$ | AOU | $PO_4$ | $NO_3$ | $SiO_4$ | $NO_2$ |
|---|---|---|---|---|---|---|---|---|---|---|---|
| (m) | (°C) | (‰) | (‰) | (ml/L) | (gm/L) | (cl/L) | (ml/L) | —— (μg at./L) —— | | | |
| 0 | 26.20 | 19.06 | 34.43 | 4.34 | 22.57 | 529.0 | .20 | -0 | -0 | -0 | -0 |
| 50 | 26.12 | 19.04 | 34.40 | 4.28 | 22.56 | 529.2 | .27 | -0 | -0 | -0 | -0 |
| 75 | 14.06 | 19.12 | 34.54 | 1.41 | 25.84 | 216.9 | 4.22 | -0 | -0 | -0 | -0 |
| 100 | 12.10 | 19.20 | 34.69 | .38 | 26.35 | 168.8 | 5.48 | -0 | -0 | -0 | -0 |
| 150 | 11.18 | 19.23 | 34.74 | .30 | 26.56 | 148.5 | 5.67 | -0 | -0 | -0 | -0 |
| 225 | 10.75 | 19.19 | 34.67 | .32 | 26.58 | 146.4 | 5.71 | -0 | -0 | -0 | -0 |
| 292 | 9.85 | 19.19 | 34.67 | .51 | 26.74 | 131.5 | 5.65 | -0 | -0 | -0 | -0 |
| 386 | 9.11 | 19.19 | 34.67 | .42 | 26.86 | 119.9 | 5.84 | -0 | -0 | -0 | -0 |
| 576 | 7.03 | 19.13 | 34.56 | .36 | 27.09 | 98.3 | 6.22 | -0 | -0 | -0 | -0 |

INTERPOLATED AND COMPUTED VALUES AT STANDARD DEPTHS

| Z | T | Cl | S | $\sigma_T$ | $\delta_T$ | $\delta$ | $\Delta D_{Z/0}$ | $\Delta D_{Z/Z\,MAX}$ | $Q_Z$ |
|---|---|---|---|---|---|---|---|---|---|
| (m) | (°C) | (‰) | (‰) | (gm/L) | (cl/T) | (cl/T) | (dyn m) | (dyn m) | (m-dynm) |
| 0 | 26.20 | 19.06 | 34.43 | 22.56 | 529.0 | 529.1 | 0 | 1.072 | 237.3 |
| 10 | 26.19 | 19.06 | 34.43 | 22.56 | 529.1 | 529.6 | .053 | 1.019 | 226.8 |
| 20 | 26.18 | 19.05 | 34.42 | 22.56 | 529.1 | 530.0 | .106 | .966 | 216.9 |
| 30 | 26.17 | 19.05 | 34.42 | 22.56 | 529.1 | 530.5 | .159 | .913 | 207.5 |
| 50 | 26.12 | 19.04 | 34.40 | 22.56 | 529.2 | 531.3 | .265 | .807 | 190.3 |
| 75 | 14.06 | 19.12 | 34.54 | 25.84 | 216.9 | 219.1 | .359 | .713 | 171.3 |
| 100 | 12.10 | 19.20 | 34.69 | 26.34 | 168.8 | 171.5 | .408 | .664 | 154.1 |
| 150 | 11.18 | 19.23 | 34.74 | 26.56 | 148.5 | 152.2 | .489 | .583 | 122.9 |
| 200 | 10.88 | 19.20 | 34.69 | 26.57 | 147.0 | 151.8 | .565 | .507 | 95.6 |
| 250 | 10.39 | 19.19 | 34.67 | 26.64 | 140.4 | 146.1 | .639 | .433 | 72.1 |
| 300 | 9.78 | 19.19 | 34.67 | 26.75 | 130.4 | 137.0 | .710 | .362 | 52.2 |
| 400 | 8.92 | 19.18 | 34.66 | 26.88 | 118.0 | 126.1 | .841 | .231 | 22.6 |
| 500 | 7.77 | 19.15 | 34.59 | 27.01 | 105.9 | 114.9 | .962 | .110 | 5.5 |
| 600 | 6.82 | 19.13 | 34.55 | 27.11 | 96.1 | 105.6 | 1.072 | 0 | 0 |

| STATION | DATE | TIME | LATITUDE | LONGITUDE | D |
|---|---|---|---|---|---|
| H 334 | FEB 22, 1964 | 0825-0906 | 11° 14.5'N | 149° 59.8'W | |

OBSERVED AND COMPUTED VALUES AT OBSERVED DEPTHS

| Z | T | Cl | S | $O_2$ | $\sigma_T$ | $\delta_T$ | AOU | $PO_4$ | $NO_3$ | $SiO_4$ | $NO_2$ |
|---|---|---|---|---|---|---|---|---|---|---|---|
| (m) | (°C) | (‰) | (‰) | (ml/L) | (gm/L) | (cl/L) | (ml/L) | (µg at./L) | | | |
| 0 | 25.60 | 18.93 | 34.20 | 4.30 | 22.57 | 528.1 | .30 | -0 | -0 | -0 | -0 |
| 49 | 24.52 | 19.02 | 34.36 | 4.44 | 23.02 | 485.0 | .23 | -0 | -0 | -0 | -0 |
| 74 | 19.51 | 19.13 | 34.56 | 4.18 | 24.57 | 337.3 | .90 | -0 | -0 | -0 | -0 |
| 99 | 14.36 | 19.03 | 34.38 | 2.26 | 25.65 | 234.8 | 3.34 | -0 | -0 | -0 | -0 |
| 148 | 11.98 | 19.22 | 34.72 | .20 | 26.40 | 164.0 | 5.67 | -0 | -0 | -0 | -0 |
| 221 | 10.95 | 19.23 | 34.74 | .40 | 26.60 | 144.5 | 5.60 | -0 | -0 | -0 | -0 |
| 307 | 10.10 | 19.21 | 34.70 | .35 | 26.72 | 132.9 | 5.77 | -0 | -0 | -0 | -0 |
| 416 | 9.24 | 19.19 | 34.67 | .30 | 26.84 | 121.9 | 5.94 | -0 | -0 | -0 | -0 |
| 601 | 7.44 | 19.14 | 34.58 | .36 | 27.04 | 102.4 | 6.15 | -0 | -0 | -0 | -0 |

INTERPOLATED AND COMPUTED VALUES AT STANDARD DEPTHS

| Z (m) | T (°C) | Cl (‰) | S (‰) | $\sigma_T$ (gm/L) | $\delta_T$ (cl/T) | $\delta$ (cl/T) | $\Delta D_{Z/0}$ (dyn m) | $\Delta D_{Z/Z\,MAX}$ (dyn m) | $Q_Z$ (m-dyn m) |
|---|---|---|---|---|---|---|---|---|---|
| 0 | 25.60 | 18.93 | 34.20 | 22.57 | 528.1 | 528.2 | 0 | 1.137 | 251.3 |
| 10 | 25.48 | 18.94 | 34.22 | 22.62 | 523.2 | 523.7 | .053 | 1.085 | 240.2 |
| 20 | 25.32 | 18.95 | 34.24 | 22.69 | 517.0 | 517.9 | .105 | 1.033 | 229.6 |
| 30 | 25.12 | 18.97 | 34.27 | 22.77 | 509.1 | 510.4 | .156 | .981 | 219.6 |
| 50 | 24.40 | 19.02 | 34.36 | 23.06 | 481.4 | 483.4 | .255 | .882 | 200.9 |
| 75 | 19.33 | 19.12 | 34.55 | 24.61 | 333.6 | 336.3 | .358 | .779 | 180.2 |
| 100 | 14.30 | 19.03 | 34.39 | 25.67 | 233.0 | 236.0 | .429 | .708 | 161.6 |
| 150 | 11.95 | 19.22 | 34.72 | 26.40 | 163.3 | 167.2 | .530 | .607 | 128.7 |
| 200 | 11.21 | 19.23 | 34.73 | 26.55 | 149.3 | 154.2 | .611 | .527 | 100.4 |
| 250 | 10.63 | 19.22 | 34.72 | 26.65 | 140.1 | 146.0 | .686 | .452 | 75.9 |
| 300 | 10.16 | 19.21 | 34.71 | 26.71 | 133.7 | 140.5 | .757 | .380 | 55.1 |
| 400 | 9.35 | 19.19 | 34.67 | 26.82 | 123.3 | 131.7 | .893 | .244 | 23.9 |
| 500 | 8.34 | 19.16 | 34.62 | 26.94 | 112.2 | 121.6 | 1.020 | .117 | 5.9 |
| 600 | 7.45 | 19.14 | 34.58 | 27.04 | 102.5 | 112.8 | 1.137 | 0 | 0 |

H 334

| STATION | DATE | TIME | LATITUDE | LONGITUDE | D |
|---|---|---|---|---|---|
| H 337 | FEB 22, 1964 | 2025-2105 | 12° 50.0'N | 151° 01.1'W | |

OBSERVED AND COMPUTED VALUES AT OBSERVED DEPTHS

| Z | T | Cl | S | $O_2$ | $\sigma_T$ | $\delta_T$ | AOU | $PO_4$ | $NO_3$ | $SiO_4$ | $NO_2$ |
|---|---|---|---|---|---|---|---|---|---|---|---|
| (m) | (°C) | (‰) | (‰) | (ml/L) | (gm/L) | (cl/L) | (ml/L) | (µg at./L) | | | |
| 0 | 24.70 | 19.11 | 34.52 | 4.48 | 23.09 | 478.5 | .17 | -0 | -0 | -0 | -0 |
| 49 | 24.54 | 19.07 | 34.45 | 4.46 | 23.09 | 479.1 | .21 | -0 | -0 | -0 | -0 |
| 73 | 24.51 | 19.16 | 34.61 | 4.37 | 23.22 | 466.5 | .29 | -0 | -0 | -0 | -0 |
| 98 | 19.85 | 19.35 | 34.96 | 4.26 | 24.79 | 316.9 | .77 | -0 | -0 | -0 | -0 |
| 147 | 13.76 | 19.42 | 35.08 | 3.12 | 26.32 | 171.2 | 2.52 | -0 | -0 | -0 | -0 |
| 218 | 11.22 | 19.04 | 34.40 | .67 | 26.29 | 174.4 | 5.31 | -0 | -0 | -0 | -0 |
| 321 | 10.04 | 19.11 | 34.52 | .24 | 26.59 | 145.3 | 5.90 | -0 | -0 | -0 | -0 |
| 417 | 8.80 | 19.10 | 34.51 | .21 | 26.78 | 127.3 | 6.10 | -0 | -0 | -0 | -0 |
| 587 | 6.85 | 19.07 | 34.45 | .46 | 27.03 | 104.0 | 6.15 | -0 | -0 | -0 | -0 |

H 337

INTERPOLATED AND COMPUTED VALUES AT STANDARD DEPTHS

| Z (m) | T (°C) | Cl (‰) | S (‰) | $\sigma_T$ (gm/L) | $\delta_T$ (cl/T) | $\delta$ (cl/T) | $\Delta D_{Z/0}$ (dyn m) | $\Delta D_{Z/Z\,MAX}$ (dyn m) | $Q_Z$ (m-dynm) |
|---|---|---|---|---|---|---|---|---|---|
| 0 | 24.70 | 19.11 | 34.52 | 23.09 | 478.5 | 478.6 | 0 | 1.231 | 270.2 |
| 10 | 24.68 | 19.10 | 34.51 | 23.09 | 478.9 | 479.4 | .048 | 1.183 | 258.2 |
| 20 | 24.66 | 19.10 | 34.50 | 23.09 | 479.0 | 479.9 | .096 | 1.135 | 246.6 |
| 30 | 24.63 | 19.09 | 34.49 | 23.09 | 479.0 | 480.3 | .144 | 1.087 | 235.5 |
| 50 | 24.54 | 19.07 | 34.46 | 23.09 | 478.7 | 480.8 | .240 | .991 | 214.7 |
| 75 | 24.29 | 19.17 | 34.64 | 23.30 | 458.5 | 461.6 | .358 | .873 | 191.4 |
| 100 | 19.55 | 19.35 | 34.95 | 24.86 | 309.7 | 313.3 | .455 | .776 | 170.7 |
| 150 | 13.63 | 19.40 | 35.05 | 26.32 | 171.4 | 175.7 | .577 | .654 | 135.0 |
| 200 | 11.78 | 19.12 | 34.54 | 26.29 | 173.7 | 178.8 | .665 | .566 | 104.5 |
| 250 | 10.80 | 19.06 | 34.44 | 26.39 | 164.1 | 170.0 | .753 | .478 | 78.4 |
| 300 | 10.25 | 19.10 | 34.50 | 26.54 | 150.4 | 157.2 | .834 | .397 | 56.5 |
| 400 | 9.00 | 19.10 | 34.51 | 26.75 | 130.1 | 138.2 | .982 | .249 | 24.2 |
| 500 | 7.76 | 19.08 | 34.47 | 26.91 | 114.9 | 123.8 | 1.113 | .118 | 5.9 |
| 600 | 6.73 | 19.07 | 34.45 | 27.04 | 102.5 | 111.9 | 1.231 | 0 | 0 |

| STATION | DATE | TIME | LATITUDE | LONGITUDE | D |
|---|---|---|---|---|---|
| H 340 | FEB 23, 1964 | 0800-0902 | 14° 23.2'N | 152° 06.6'W | |

OBSERVED AND COMPUTED VALUES AT OBSERVED DEPTHS

| Z (m) | T (°C) | Cl (‰) | S (‰) | $O_2$ (ml/L) | $\sigma_T$ (gm/L) | $\delta_T$ (cl/L) | AOU (ml/L) | $PO_4$ | $NO_3$ | $SiO_4$ | $NO_2$ |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | (µg at./L) | | | |
| 0 | 24.50 | 18.97 | 34.27 | 4.41 | 22.96 | 491.0 | .26 | -0 | -0 | -0 | -0 |
| 48 | 24.34 | 18.98 | 34.29 | 4.42 | 23.02 | 485.1 | .27 | -0 | -0 | -0 | -0 |
| 72 | 23.56 | 19.29 | 34.85 | 4.53 | 23.68 | 422.8 | .20 | -0 | -0 | -0 | -0 |
| 96 | 21.65 | 19.40 | 35.05 | 4.51 | 24.37 | 356.6 | .36 | -0 | -0 | -0 | -0 |
| 144 | 17.26 | 19.24 | 34.76 | 4.01 | 25.29 | 269.5 | 1.27 | -0 | -0 | -0 | -0 |
| 216 | 11.35 | 19.03 | 34.38 | 1.64 | 26.25 | 178.0 | 4.33 | -0 | -0 | -0 | -0 |
| 318 | 9.28 | 19.12 | 34.54 | .63 | 26.73 | 131.9 | 5.61 | -0 | -0 | -0 | -0 |
| 422 | 8.31 | 19.15 | 34.60 | .45 | 26.93 | 113.3 | 5.93 | -0 | -0 | -0 | -0 |
| 600 | 6.55 | 19.11 | 34.52 | .61 | 27.13 | 94.8 | 5.05 | -0 | -0 | -0 | -0 |

INTERPOLATED AND COMPUTED VALUES AT STANDARD DEPTHS

| Z (m) | T (°C) | Cl (‰) | S (‰) | $\sigma_T$ (gm/L) | $\delta_T$ (cl/T) | $\delta$ (cl/T) | $\Delta D_{Z/0}$ (dyn m) | $\Delta D_{Z/Z\,MAX}$ (dyn m) | $Q_Z$ (m-dyn m) |
|---|---|---|---|---|---|---|---|---|---|
| 0 | 24.50 | 18.97 | 34.27 | 22.96 | 491.0 | 491.1 | 0 | 1.257 | 263.8 |
| 10 | 24.48 | 18.97 | 34.27 | 22.97 | 490.3 | 490.8 | .049 | 1.208 | 251.5 |
| 20 | 24.46 | 18.97 | 34.28 | 22.98 | 489.4 | 490.3 | .098 | 1.159 | 239.6 |
| 30 | 24.43 | 18.97 | 34.28 | 22.99 | 488.3 | 489.6 | .147 | 1.110 | 228.3 |
| 50 | 24.30 | 18.99 | 34.31 | 23.05 | 482.2 | 484.2 | .245 | 1.013 | 207.0 |
| 75 | 23.39 | 19.30 | 34.87 | 23.74 | 416.3 | 419.3 | .357 | .900 | 183.1 |
| 100 | 21.35 | 19.39 | 35.03 | 24.44 | 350.1 | 353.9 | .454 | .803 | 161.9 |
| 150 | 16.67 | 19.21 | 34.70 | 25.38 | 260.3 | 265.2 | .609 | .648 | 125.6 |
| 200 | 12.47 | 19.05 | 34.42 | 26.06 | 195.4 | 200.7 | .725 | .532 | 96.1 |
| 250 | 10.57 | 19.06 | 34.43 | 26.43 | 160.6 | 166.4 | .817 | .440 | 71.8 |
| 300 | 9.59 | 19.10 | 34.51 | 26.66 | 138.9 | 145.3 | .895 | .362 | 51.7 |
| 400 | 8.49 | 19.14 | 34.58 | 26.89 | 116.8 | 124.6 | 1.030 | .227 | 22.2 |
| 500 | 7.46 | 19.13 | 34.55 | 27.02 | 104.4 | 113.0 | 1.149 | .108 | 5.4 |
| 600 | 6.55 | 19.11 | 34.52 | 27.12 | 94.8 | 104.0 | 1.257 | 0 | 0 |

| STATION | DATE | TIME | LATITUDE | LONGITUDE | D |
|---|---|---|---|---|---|
| H 343 | FEB 23, 1964 | 2025- | 15° 56.8'N | 153° 13.1'W | |

OBSERVED AND COMPUTED VALUES AT OBSERVED DEPTHS

| Z (m) | T (°C) | Cl (‰) | S (‰) | $O_2$ (ml/L) | $\sigma_T$ (gm/L) | $\delta_T$ (cl/L) | AOU (ml/L) | $PO_4$ | $NO_3$ | $SiO_4$ | $NO_2$ |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | (µg at./L) | | | |
| 0 | 23.70 | 18.91 | 34.16 | 4.48 | 23.12 | 476.2 | .26 | -0 | -0 | -0 | -0 |
| 49 | 23.57 | 18.89 | 34.13 | 4.53 | 23.13 | 475.2 | .22 | -0 | -0 | -0 | -0 |
| 73 | 23.41 | 18.92 | 34.18 | 4.46 | 23.22 | 466.8 | .30 | -0 | -0 | -0 | -0 |
| 98 | 22.94 | 19.17 | 34.63 | 4.54 | 23.69 | 421.3 | .24 | -0 | -0 | -0 | -0 |
| 147 | 20.21 | 19.02 | 34.36 | 4.18 | 24.24 | 369.1 | .84 | -0 | -0 | -0 | -0 |
| 210 | 14.18 | 19.12 | 34.54 | 3.91 | 25.81 | 219.3 | 1.71 | -0 | -0 | -0 | -0 |
| 303 | 10.49 | 19.19 | 34.67 | .98 | 26.63 | 142.0 | 5.09 | -0 | -0 | -0 | -0 |
| 395 | 8.82 | 19.15 | 34.60 | .58 | 26.85 | 120.9 | 5.73 | -0 | -0 | -0 | -0 |
| 584 | 6.56 | 19.10 | 34.51 | .53 | 27.11 | 96.2 | 6.13 | -0 | -0 | -0 | -0 |

INTERPOLATED AND COMPUTED VALUES AT STANDARD DEPTHS

| Z (m) | T (°C) | Cl (‰) | S (‰) | $\sigma_T$ (gm/L) | $\delta_T$ (cl/T) | $\delta$ (cl/T) | $\Delta D_{Z/0}$ (dyn m) | $\Delta D_{Z/Z\,MAX}$ (dyn m) | $Q_Z$ (m-dyn m) |
|---|---|---|---|---|---|---|---|---|---|
| 0 | 23.70 | 18.91 | 34.16 | 23.12 | 476.2 | 476.3 | 0 | 1.384 | 286.2 |
| 10 | 23.69 | 18.91 | 34.16 | 23.12 | 476.1 | 476.6 | .048 | 1.337 | 272.6 |
| 20 | 23.67 | 18.90 | 34.15 | 23.12 | 475.9 | 476.8 | .095 | 1.289 | 259.5 |
| 30 | 23.64 | 18.90 | 34.15 | 23.12 | 475.7 | 477.0 | .143 | 1.241 | 246.8 |
| 50 | 23.57 | 18.89 | 34.13 | 23.13 | 475.0 | 477.0 | .238 | 1.146 | 223.0 |
| 75 | 23.38 | 18.93 | 34.20 | 23.24 | 464.6 | 467.6 | .356 | 1.028 | 195.8 |
| 100 | 22.87 | 19.17 | 34.63 | 23.71 | 419.7 | 423.5 | .468 | .916 | 171.5 |
| 150 | 19.98 | 19.02 | 34.36 | 24.30 | 363.3 | 368.7 | .666 | .718 | 130.6 |
| 200 | 15.09 | 19.09 | 34.49 | 25.58 | 241.8 | 247.8 | .820 | .564 | 98.6 |
| 250 | 12.43 | 19.14 | 34.58 | 26.20 | 182.5 | 189.1 | .929 | .455 | 73.1 |
| 300 | 10.59 | 19.19 | 34.66 | 26.60 | 144.1 | 151.1 | 1.014 | .370 | 52.5 |
| 400 | 8.75 | 19.15 | 34.59 | 26.86 | 120.1 | 128.0 | 1.154 | .230 | 22.4 |
| 500 | 7.46 | 19.11 | 34.53 | 27.01 | 106.0 | 114.6 | 1.275 | .109 | 5.5 |
| 600 | 6.40 | 19.10 | 34.50 | 27.13 | 94.5 | 103.6 | 1.384 | 0 | 0 |

# APPENDIX B—APENDICE B

## SURFACE OBSERVATIONS—OBSERVACIONES DE LA SUPERFICIE

### Explanation of table headings

### Explicación de los títulos de las tablas

| | |
|---|---|
| Time | Local times of start and finish of observations<br>Hora local del comienzo y de la terminación de las observaciones |
| Lat | Latitude—Latitud |
| Long | Longitude—Longitud |
| Sea T (C) | Sea-surface temperature, degrees Celsius<br>Temperatura de la superficie del mar, centígrados |
| Cl (‰) | Surface chlorinity, grams per kilogram<br>Clorinidad de la superficie, gramos por kilogramo |
| S (‰) | Surface salinity, grams per kilogram<br>Salinidad de la superficie, gramos por kilogramo |
| $O_2$ (ml/L) | Surface dissolved-oxygen concentration, milliliters per liter<br>Concentración de oxígeno disuelto en la superficie, mililitros por litro |
| Air T (C) | Air temperature, degrees Celsius<br>Temperatura del aire, centígrados |
| Baro (mb) | Barometric pressure (units and tens only; 1017 = 17), millibars<br>Presión barométrica (unidades y décimos solamente; 1017 = 17), milibarras |
| Clouds | |
| *Type* | Predominant type of cloud cover[1]<br>Tipo predominante de la cubierta de nubes[1] |
| *Amount* | Amount of sky covered by clouds, tenths<br>Porción del cielo cubierto por nubes, décimos |
| Weather | Weather at time of observation[2]<br>Tiempo en la hora de la observación[2] |
| Wind | |
| *Dir* | Wind direction, tens of degrees true (NNW ≈340° =34)<br>Dirección del viento, décimos de grados verdaderos (NNW ≈340° =34) |
| *Force* | Wind force, Beaufort scale<br>Fuerza del viento, escala de Beaufort |
| Sea | |
| *Waves* | Wave height, Beaufort scale<br>Altura de las ondas, escala de Beaufort |
| *Swell* | Height of swell, Beaufort scale<br>Altura del oleaje, escala de Beaufort |

### Explanation of notes

### Explicación de las notas

a) Questionable value 20.88‰—Valor cuestionable de 20.88‰

[1] Coded according to U.S. Navy Hydrographic Office (1960). Symbols appearing in data are: 1 = Cirrus; 4 = Altocumulus; 5 = Altostratus; 6 = Stratocumulus; 7 = Nimbostratus; 8 = Cumulus, Fractocumulus; 9 = Cumulonimbus; 0 = Stratus, Fractostratus.

[1] En código del U.S. Navy Hydrographic Office (1960). Los símbolos que aparecen en los datos son: 1 = Cirrus; 4 = Altocúmulus; 5 = Altostratus; 6 = Stratocúmulus; 7 = Nimbostratus, 8 = Cúmulus, Fractocúmulus; 9 = Cúmulonimbus; 0 = Stratus, Fractostratus

[2] Coded according to U.S. Navy Hydrographic Office (1960). Symbols appearing in data are: 00 = Blue sky whether clear or hazy atmosphere; 01 = Fair, few or scattered clouds, also mainly cloudy; 02 = Broken clouds; 03 = Overcast sky; 18 = Squalls; 51 = Drizzle or fine rain; 61 = Rain

[2] En código del U.S. Navy Hydrographic Office (1960). Los símbolos que aparecen en los datos son: 00 = Cielo azul, sea claro o atmósfera brumosa; 01 = Claro, pocas nubes o esparcidas, también principalmente nublado; 02 = Nubes interrumpidas; 03 = Cielo nublado; 18 = Chubascos; 51 = Llovizna o lluvia liviana; 61 = Lluvia.

SURFACE OBSERVATIONS

| STATION | DATE | TIME | LAT | LONG | SEA T (°C) | Cl (‰) | S (‰) | $O_2$ (ml/L) | AIR T (°C) | BARO (mb) | CLOUDS TYPE | CLOUDS AMOUNT | WEATHER | WIND DIR | WIND FORCE | SEA WAVES | SEA SWELL |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| H 001 | OCT 6,1963 | 1220-1320 | 10-14.1N | 172-50.0E | 29.1 | 18.90 | 34.14 | 4.92 | 29.5 | 08 | 8,5 | 7 | 01 | 14 | 1 | 1 | 1 |
| H 002 | OCT 6,1963 | 2020-2035 | 9-12.0N | 173-33.8E | 29.2 | | | | 27.5 | 08 | 8,5 | 6 | 01 | 27 | 3 | 3 | 1 |
| H 003 | OCT 7,1963 | 0358-0406 | 8-02.8N | 174-23.8E | 28.8 | 18.77 | 33.91 | | 26.6 | 08 | | 8 | 01 | 02 | 2 | 1 | 1 |
| H 004 | OCT 7,1963 | 1200-1318 | 6-49.0N | 175-15.0E | 30.1 | 18.73 | 33.84 | 4.42 | 31.0 | 09 | 8,5 | 3 | 00 | 02 | 1 | 1 | 1 |
| H 005 | OCT 7,1963 | 2015-2028 | 5-42.3N | 176-06.2E | 29.2 | 18.68 | 33.75 | 4.33 | 29.9 | 09 | 8,5 | 4 | 01 | 09 | 1 | 1 | 1 |
| H 006 | OCT 8,1963 | 0400-0410 | 4-29.2N | 176-57.0E | 29.5 | 18.73 | 33.84 | 4.42 | 27.0 | 08 | | 8 | 01 | 02 | 2 | 1 | 1 |
| H 007 | OCT 8,1963 | 1200-1310 | 3-09.5N | 177-48.0E | 30.7 | 19.26 | 34.79 | 4.43 | 23.9 | 08 | 8,5 | 3 | 00 | 32 | 1 | 1 | 1 |
| H 008 | OCT 8,1963 | 2015-2025 | 2-01.1N | 178-22.5E | 29.6 | 19.37 | 34.99 | 4.31 | 28.3 | 08 | 2,8 | 4 | 01 | 18 | 2 | 1 | 1 |
| H 009 | OCT 9,1963 | 0358-0409 | 0-53.5N | 178-56.3E | 29.2 | 19.37 | 34.99 | 4.46 | 28.0 | 07 | | 2 | 00 | 32 | 1 | 1 | 1 |
| H 010 | OCT 9,1963 | 1200-1300 | 0-18.0S | 179-47.0E | 29.3 | 19.44 | 35.12 | 4.47 | 29.0 | 08 | 8,5 | 3 | 01 | 11 | 2 | 1 | 1 |
| H 011 | OCT 8,1963 | 2015-2032 | 1-15.4S | 179-36.0W | 29.0 | 19.57 | 35.35 | 4.58 | 28.0 | 08 | 8,5 | 6 | 01 | 09 | 3 | 3 | 1 |
| H 012 | OCT 9,1963 | 0400-0409 | 2-10.0S | 178-56.0W | 29.0 | 19.55 | 35.32 | 4.54 | 28.3 | 07 | 8,5 | 3 | 01 | 11 | 4 | 3 | 1 |
| H 013 | OCT 9,1963 | 1230-1310 | 3-18.8S | 178-14.0W | 29.6 | 19.56 | 35.34 | 4.65 | 29.5 | 09 | 8,5 | 7 | 01 | 09 | 4 | 3 | 1 |
| H 014 | OCT 9,1963 | 2020-2030 | 4-18.3S | 177-09.2W | 29.4 | 19.66 | 35.52 | 4.48 | 28.3 | 08 | | 7 | 01 | 11 | 4 | 3 | 1 |
| H 015 | OCT 10,1963 | 0400-0409 | 5-28.3S | 176-48.0W | 29.3 | 19.67 | 35.53 | 4.45 | 27.9 | 08 | 8,5 | 8 | 01 | 11 | 3 | 3 | 1 |
| H 016 | OCT 10,1963 | 1230-1315 | 6-49.7S | 176-05.0W | 29.6 | 19.66 | 35.52 | 4.56 | 31.0 | 09 | 8,5 | 7 | 01 | 07 | 3 | 2 | 1 |
| H 017 | OCT 10,1963 | 2020-2029 | 7-59.0S | 175-26.3W | 29.3 | 19.67 | 35.53 | 4.44 | 30.0 | 10 | 5,2 | 7 | 01 | 09 | 2 | 2 | 1 |
| H 018 | OCT 11,1963 | 0400-0410 | 9-07.8S | 174-38.6W | 28.7 | 19.66 | 35.52 | 4.43 | 27.0 | 09 | 8 | 2 | 00 | 07 | 2 | 2 | 1 |
| H 019 | OCT 11,1963 | 1220-1345 | 10-23.7S | 173-49.2W | 29.1 | 19.66 | 35.52 | 4.42 | 29.6 | 11 | 5,0 | 2 | 00 | 09 | 2 | 1 | 1 |
| H 020 | OCT 11,1963 | 2015-2025 | 11-29.2S | 173-07.0W | 28.8 | 19.82 | 35.81 | 4.41 | 28.0 | 11 | 8,1 | 2 | 00 | 09 | 2 | 2 | 1 |
| H 021 | OCT 12,1963 | 0400-0410 | 12-36.3S | 172-14.8W | 28.2 | 19.82 | 35.81 | 4.46 | 27.0 | 11 | 5,8 | 2 | 00 | 07 | 2 | 2 | 1 |
| H 022 | OCT 12,1963 | 1225-1310 | 13-42.2S | 171-13.4W | 28.9 | 19.81 | 35.79 | 4.38 | 29.9 | 12 | 5,8 | 2 | 00 | 11 | 2 | 1 | 1 |
| H 023 | OCT 12,1963 | 1840-1850 | 14-20.9S | 170-35.2W | 28.0 | | | | 26.8 | 12 | 8,5 | 2 | 00 | 11 | 1 | 1 | 1 |
| H 024 | OCT 17,1963 | 2020-2030 | 14-37.0S | 169-37.6W | 27.9 | 19.84 | 35.84 | 4.27 | 27.3 | 10 | 8 | 2 | 00 | 11 | 4 | 3 | 1 |
| H 025 | OCT 18,1963 | 0400-0410 | 15-02.2S | 168-15.4W | 27.8 | 19.89 | 35.93 | 4.36 | 26.5 | 07 | 8,0 | | 01 | 07 | 3 | 3 | 2 |
| H 026 | OCT 18,1963 | 1220-1300 | 15-20.3S | 166-45.8W | 27.8 | 19.96 | 36.06 | 4.47 | 29.5 | 09 | | | 01 | 07 | 3 | 2 | |
| H 027 | OCT 18,1963 | 2020 | 15-28.7S | 165-24.3W | 27.6 | 19.94 | 36.02 | 4.50 | 27.5 | 10 | | | 00 | 07 | 4 | 3 | |
| H 028 | OCT 19,1963 | 0400-0410 | 15-34.0S | 164-11.9W | 27.7 | 19.95 | 36.04 | 4.49 | 26.4 | 09 | | | 01 | 07 | 3 | 3 | |
| H 029 | OCT 19,1963 | 1225-1300 | 15-51.0S | 162-43.5W | 27.6 | 19.97 | 36.08 | 4.54 | 26.8 | 11 | | | 01 | 04 | 4 | 2 | |
| H 030 | OCT 19,1963 | 2020 | 16-00.9S | 161-26.7W | 27.3 | 19.96 | 36.06 | 4.54 | 27.3 | 11 | | | 18 | 04 | 4 | 3 | |
| H 031 | OCT 20,1963 | 0400 | 16-18.2S | 160-04.0W | 27.2 | a) | | 4.52 | 26.7 | 10 | | | 18 | 04 | 4 | 3 | |
| H 032 | OCT 20,1963 | 1220-1300 | 16-33.0S | 158-36.5W | 27.1 | 19.96 | 36.06 | 4.58 | 27.9 | 12 | | | 18 | 02 | 3 | 2 | |
| H 033 | OCT 20,1963 | 2020 | 16-42.2S | 157-13.0W | 27.5 | 20.07 | 36.26 | 4.56 | 26.6 | 11 | | | 18 | 02 | 2 | 1 | |
| H 034 | OCT 21,1963 | 0400 | 16-51.2S | 155-49.2W | 27.2 | 20.08 | 36.27 | 4.53 | 24.1 | 09 | | | 18 | 20 | 4 | 3 | |
| H 035 | OCT 21,1963 | 1220-1310 | 17-07.0S | 154-17.0W | 27.0 | 20.08 | 36.27 | 4.55 | 25.9 | 10 | | | 18 | 32 | 4 | 4 | |
| H 036 | OCT 21,1963 | 2020 | 17-13.6S | 153-01.2W | 26.9 | 20.11 | 36.33 | 4.53 | 22.8 | 11 | | | 51 | 22 | 3 | 3 | |
| H 037 | OCT 22,1963 | 0400 | 17-21.5S | 151-34.1W | 26.4 | 20.08 | 36.27 | 4.60 | 24.3 | 09 | | | | 16 | 5 | | |
| H 038 | OCT 22,1963 | 1220-1305 | 17-20.3S | 150-04.0W | 27.4 | 20.14 | 36.38 | 4.53 | 26.9 | 10 | | | 18 | 11 | 2 | 2 | |
| H 039 | OCT 28,1963 | 2010-2025 | 18-15.0S | 148-14.0W | 26.0 | 20.09 | 36.29 | 4.60 | 24.0 | 14 | | | 18 | 16 | 5 | 4 | |
| H 040 | OCT 29,1963 | 0400-0410 | 18-55.0S | 147-15.0W | 25.9 | 20.17 | 36.44 | 4.72 | 24.0 | 13 | | | 18 | 14 | 5 | 5 | |
| H 041 | OCT 29,1963 | 1200-1300 | 19-40.2S | 146-04.1W | 25.4 | 20.07 | 36.26 | 4.67 | 25.5 | 14 | | | 18 | 14 | 5 | 5 | |
| H 042 | OCT 29,1963 | 2010 | 20-18.0S | 145-03.7W | 25.3 | 20.11 | 36.33 | 4.64 | 22.3 | 16 | | | | 14 | 6 | 5 | |
| H 043 | OCT 30,1963 | 0400 | 20-59.0S | 143-59.0W | 24.1 | 19.85 | 35.86 | 4.90 | 24.2 | 14 | | | 18 | 14 | 6 | 4 | |
| H 044 | OCT 30,1963 | 1200 | 21-43.8S | 142-46.2W | 23.7 | 19.83 | 35.82 | 4.79 | 22.5 | 16 | | | 18 | 11 | 4 | | |
| H 045 | OCT 30,1963 | 2010 | 22-28.8S | 141-33.2W | 24.4 | 19.95 | 36.04 | 4.91 | 22.0 | 18 | | | | 09 | 4 | | |
| H 046 | OCT 31,1963 | 0400 | 23-09.0S | 140-25.0W | 24.0 | 19.91 | 35.97 | 4.77 | 21.3 | 15 | | | 18 | 04 | 6 | 4 | |
| H 047 | OCT 31,1963 | 1200-1300 | 23-53.8S | 139-09.4W | 23.4 | 19.83 | 35.82 | 4.84 | 22.8 | 19 | | | 18 | 07 | 3 | 3 | |
| H 048 | OCT 31,1963 | 2010 | 24-32.8S | 138-02.7W | 22.4 | 19.70 | 35.59 | 4.89 | 21.1 | 20 | | | 18 | 07 | 4 | 4 | |
| H 049 | NOV 1,1963 | 0600-0650 | 24-55.7S | 137-03.2W | 21.6 | 19.67 | 35.53 | 5.06 | 20.8 | 20 | | | 18 | 07 | 4 | 4 | |
| H 050 | NOV 1,1963 | 2000 | 25-35.0S | 136-19.0W | 22.5 | 19.73 | 35.64 | 4.88 | 21.0 | 21 | | | 18 | 09 | 5 | 4 | |
| H 051 | NOV 2,1963 | 0400 | 26-16.0S | 135-07.6W | 21.7 | 19.68 | 35.55 | 4.96 | 19.8 | 19 | | | 61 | 09 | 4 | 4 | |
| H 052 | NOV 2,1963 | 1200-1250 | 26-59.1S | 133-55.8W | 20.7 | 19.67 | 35.53 | 5.08 | 19.0 | 21 | | | 61 | 09 | 5 | 4 | |
| H 053 | NOV 2,1963 | 2010 | 27-31.1S | 132-00.0W | 20.8 | 19.62 | 35.44 | 5.08 | 19.2 | 22 | | | 18 | 09 | 5 | 4 | |
| H 054 | NOV 3,1963 | 0600-0650 | 28-21.7S | 132-03.3W | 19.8 | 19.67 | 35.53 | 5.26 | 18.8 | 20 | | | 18 | 09 | 4 | 4 | |
| H 055 | NOV 3,1963 | 2010 | 29-01.2S | 131-04.1W | 18.6 | 19.54 | 35.30 | 5.28 | 18.3 | 18 | | | 01 | 11 | 5 | 4 | |
| H 056 | NOV 4,1963 | 0400 | 29-37.0S | 129-53.5W | 19.2 | 19.53 | 35.28 | 5.25 | 17.7 | 15 | | | | 14 | 3 | | |
| H 057 | NOV 4,1963 | 1200-1250 | 30-29.0S | 128-31.0W | 19.4 | 19.55 | 35.32 | 5.27 | 18.0 | 15 | | | 01 | 18 | 3 | 3 | |

SURFACE OBSERVATIONS

| STATION | DATE | TIME | LAT | LONG | SEA T | Cl | S | $O_2$ | AIR T | BARO | CLOUDS | | WEATHER | WIND | | SEA | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | (°C) | (‰) | (‰) | (ml/L) | (°C) | (mb) | TYPE | AMOUNT | | DIR | FORCE | WAVES | SWELL |
| H 058 | NOV 4,1963 | 2010 | 31-01.6S | 127-14.9W | 19.2 | 19.60 | 35.41 | 5.32 | 17.3 | 15 | | | 01 | 20 | 2 | 3 | |
| H 059 | NOV 5,1963 | 0600-0710 | 30-57.5S | 126-51.5W | 19.0 | 19.57 | 35.35 | 5.28 | 17.0 | 15 | | | 01 | 22 | 4 | 4 | |
| H 060 | NOV 5,1963 | 2010 | 31-14.0S | 127-12.0W | 17.3 | 19.46 | 35.16 | 5.48 | 15.0 | 21 | | | 01 | 18 | 6 | 6 | |
| H 061 | NOV 6,1963 | 0400 | 31-40.0S | 127-00.5W | 17.8 | 19.47 | 35.17 | 5.51 | 17.0 | 22 | | | 18 | 20 | 5 | 5 | |
| H 062 | NOV 6,1963 | 1200-1250 | 32-25.1S | 126-09.0W | 18.1 | 19.52 | 35.26 | 5.43 | 15.6 | 25 | | | 01 | 20 | 3 | 3 | |
| H 063 | NOV 6,1963 | 2010 | 32-37.9S | 125-00.9W | 16.7 | 19.37 | 34.99 | 5.44 | 15.0 | 25 | | | 01 | 20 | 5 | 5 | |
| H 064 | NOV 7,1963 | 0605-0650 | 32-46.7S | 123-19.8W | 16.9 | 19.37 | 34.99 | 5.63 | 14.3 | 27 | | | 01 | 18 | 5 | 3 | |
| H 065 | NOV 7,1963 | 2010 | 33-22.0S | 122-43.6W | 17.1 | 19.39 | 35.03 | 5.56 | 14.5 | 32 | | | 01 | 11 | 4 | 4 | |
| H 066 | NOV 8,1963 | 0400 | 34-02.0S | 121-21.3W | 16.6 | 19.38 | 35.01 | 5.61 | 13.9 | 32 | | | 18 | 14 | 2 | 2 | |
| H 067 | NOV 8,1963 | 1200-1250 | 34-46.0S | 119-52.0W | 16.6 | 19.37 | 34.99 | 5.60 | 15.0 | 32 | | | 01 | 16 | 3 | 2 | |
| H 068 | NOV 8,1963 | 2010 | 35-22.2S | 118-33.4W | 16.2 | | | 5.69 | 13.0 | 32 | | | 51 | 16 | 3 | 2 | |
| H 069 | NOV 9,1963 | 0605-0720 | 35-45.8S | 116-46.8W | 15.2 | 19.19 | 34.67 | 5.80 | 13.5 | 32 | | | 18 | 16 | 2 | 2 | |
| H 070 | NOV 9,1963 | 2010 | 36-37.0S | 116-02.0W | 15.0 | 19.24 | 34.76 | 5.77 | 13.0 | 32 | | | 03 | 14 | 2 | 2 | |
| H 071 | NOV 10,1963 | 0610-0650 | 37-02.4S | 114-40.6W | 14.6 | 19.06 | 34.43 | 5.83 | 12.0 | 31 | | | 01 | 11 | 2 | 2 | |
| H 072 | NOV 10,1963 | 2010 | 37-26.0S | 114-20.0W | 16.6 | 19.06 | 34.43 | 5.74 | 13.0 | 30 | | | 03 | | 0 | 0 | |
| H 073 | NOV 11,1963 | 0400 | 38-12.0S | 112-58.0W | 14.2 | | | 5.97 | 12.3 | 28 | | | 03 | 36 | 2 | 1 | |
| H 074 | NOV 11,1963 | 1200 | 39-13.3S | 111-22.9W | 14.4 | 19.03 | 34.38 | 5.95 | | | | | 01 | 29 | 2 | | |
| H 075 | NOV 11,1963 | 2010 | 39-55.2S | 109-54.5W | 14.0 | 18.89 | 34.13 | 5.99 | 12.5 | 26 | | | 03 | 27 | 2 | 2 | |
| H 076 | NOV 12,1963 | 0555-0630 | 40-07.4S | 109-22.2W | 13.8 | 18.94 | 34.22 | 5.94 | 11.0 | 24 | | | 51 | 18 | 4 | 3 | |
| H 077 | NOV 12,1963 | 2010 | 39-49.8S | 108-38.7W | 13.6 | 18.91 | 34.16 | 6.09 | 11.3 | 27 | | | 01 | 16 | 4 | 3 | |
| H 078 | NOV 13,1963 | 0600-0650 | 39-10.2S | 106-43.0W | 13.0 | 18.91 | 34.16 | 6.13 | 10.6 | 28 | | | 01 | 16 | 3 | 3 | |
| H 079 | NOV 13,1963 | 2000 | 39-18.2S | 105-43.8W | 13.3 | 18.89 | 34.13 | 6.02 | 11.0 | 31 | | | 00 | 18 | 3 | 2 | |
| H 080 | NOV 14,1963 | 0400 | 39-01.0S | 103-57.2W | 13.6 | 18.90 | 34.14 | 5.90 | 10.6 | 31 | | | 01 | 18 | 2 | 1 | |
| H 081 | NOV 14,1963 | 1200 | 38-42.4S | 102-06.4W | 13.5 | 18.90 | 34.14 | 6.13 | 11.8 | 34 | | | 01 | 18 | 2 | 2 | |
| H 082 | NOV 14,1963 | 2000-2010 | 38-32.3S | 101-20.7W | 14.4 | 18.92 | 34.18 | 5.94 | 10.5 | 34 | | | 03 | | 0 | 1 | |
| H 083 | NOV 15,1963 | 0615-0700 | 38-12.9S | 101-02.8W | 13.7 | 18.90 | 34.14 | 6.04 | 11.3 | 35 | | | 03 | | 0 | 1 | |
| H 084 | NOV 15,1963 | 2010 | 37-36.6S | 101-07.0W | 14.3 | 18.90 | 34.14 | 5.99 | 12.1 | 36 | | | 01 | | 0 | 0 | |
| H 085 | NOV 16,1963 | 0400-0410 | 36-10.0S | 101-07.0W | 15.1 | 18.96 | 34.25 | 5.76 | 13.7 | 34 | | | 03 | 09 | 2 | 1 | |
| H 086 | NOV 16,1963 | 1200-1238 | 34-44.3S | 101-00.9W | 16.1 | 19.02 | 34.36 | 5.80 | 15.0 | 35 | | | 01 | 07 | | 2 | |
| H 087 | NOV 16,1963 | 2000-2010 | 34-43.2S | 101-02.2W | 15.5 | | | | 15.0 | 35 | | | 01 | 07 | 2 | 2 | |
| H 088 | NOV 17,1963 | 0545 | 34-38.3S | 101-32.6W | 15.4 | 19.05 | 34.42 | 5.77 | 14.6 | 32 | | | 01 | 07 | 2 | 2 | |
| H 089 | NOV 17,1963 | 2010 | 34-39.8S | 99-53.8W | 15.9 | 19.10 | 34.51 | 5.79 | 15.0 | 32 | | | 00 | 02 | 4 | 4 | |
| H 090 | NOV 18,1963 | 0400-0410 | 34-21.8S | 98-17.0W | 15.6 | 19.09 | 34.49 | 5.74 | 14.4 | 31 | | | 01 | 18 | 3 | 2 | |
| H 091 | NOV 18,1963 | 1200 | 34-05.3S | 96-27.2W | 16.2 | 18.98 | 34.29 | 5.89 | 15.3 | 32 | | | 01 | 34 | 2 | 2 | |
| H 092 | NOV 18,1963 | 2010 | 33-47.5S | 94-51.2W | 17.2 | 19.19 | 34.67 | 5.35 | 15.0 | 32 | | | 00 | | 0 | 1 | |
| H 093 | NOV 19,1963 | 0610 | 33-59.2S | 94-08.0W | 15.8 | 18.95 | 34.23 | 5.66 | 14.5 | 31 | | | 00 | 36 | 1 | 1 | |
| H 094 | NOV 19,1963 | 2000 | 33-27.5S | 92-48.2W | | 19.18 | 34.65 | 5.38 | 15.0 | 30 | | | 00 | 29 | 1 | 1 | |
| H 095 | NOV 20,1963 | 0830-0909 | 32-59.2S | 90-19.1W | 16.7 | 19.03 | 34.38 | 5.50 | 18.8 | 29 | | | 01 | | 0 | | |
| H 096 | NOV 20,1963 | 2015-2100 | 32-22.9S | 87-50.8W | 17.1 | 19.18 | 34.65 | 5.45 | 15.0 | 26 | | | 01 | 32 | 1 | 1 | |
| H 097 | NOV 21,1963 | 0600-0640 | 32-22.3S | 86-40.0W | 16.5 | 19.05 | 34.42 | 5.53 | 16.7 | 22 | | | 01 | 27 | 3 | 1 | |
| H 098 | NOV 21,1963 | 2015-2100 | 32-16.0S | 85-43.8W | 16.8 | 19.13 | 34.56 | 5.42 | 15.5 | 20 | | | 00 | 25 | 3 | 3 | |
| H 099 | NOV 22,1963 | 0830-0915 | 32-43.1S | 83-18.8W | 16.5 | 19.07 | 34.45 | 5.48 | 16.8 | 20 | | | 01 | 22 | 2 | 2 | |
| H 100 | NOV 22,1963 | 2010-2055 | 33-08.5S | 81-03.0W | 16.3 | 18.83 | 34.02 | 5.55 | 15.2 | 20 | | | 01 | 27 | 2 | 2 | |
| H 101 | NOV 23,1963 | 0830-0900 | 33-14.2S | 78-28.2W | 15.8 | 18.88 | 34.11 | 5.62 | 15.0 | 20 | | | 00 | 25 | 2 | 1 | |
| H 102 | NOV 23,1963 | 2010-2100 | 33-17.5S | 75-55.0W | 16.6 | 18.77 | 33.91 | 5.49 | 15.4 | 18 | | | 01 | 20 | 2 | 2 | |
| H 103 | DEC 5,1963 | 0830-0934 | 37-05.8S | 77-55.2W | 15.4 | 18.80 | 33.96 | 6.02 | 17.0 | 21 | 0 | 8 | 03 | 18 | 4 | 3 | 2 |
| H 104 | DEC 5,1963 | 2010-2140 | 37-22.8S | 80-09.9W | 15.0 | 18.85 | 34.05 | 6.01 | 14.5 | 18 | 4,5 | 3 | 00 | 29 | 5 | 4 | 3 |
| H 105 | DEC 6,1963 | 0840-0935 | 37-49.1S | 82-14.7W | 15.1 | 18.90 | 34.14 | 5.96 | 14.4 | 16 | 4,5 | 3 | 00 | 20 | 4 | 4 | 3 |
| H 106 | DEC 6,1963 | 2000-2050 | 38-06.2S | 84-13.2W | 14.5 | 18.82 | 34.00 | 5.99 | 12.2 | 20 | 4,5 | 8 | 01 | 18 | 5 | 4 | 3 |
| H 107 | DEC 7,1963 | 0835-0920 | 38-45.5S | 84-24.2W | 13.8 | 18.84 | 34.04 | 6.07 | 11.8 | 26 | 4,5 | 6 | 01 | 16 | 6 | 3 | 4 |
| H 108 | DEC 7,1963 | 2000-2055 | 39-36.5S | 88-22.0W | 14.3 | 18.87 | 34.09 | 6.06 | 11.0 | 27 | 5,4 | 5 | 02 | 20 | 1 | 1 | 3 |
| H 109 | DEC 8,1963 | 0606-0657 | 40-32.8S | 89-43.8W | 12.9 | 18.84 | 34.04 | 6.21 | 11.0 | 26 | 6,0 | 10 | 03 | 32 | 1 | 1 | 2 |
| H 110 | DEC 8,1963 | 2000-2045 | 39-28.0S | 90-35.5W | 13.9 | 18.83 | 34.02 | 5.97 | 12.0 | 22 | 6,0 | 10 | 03 | 34 | 3 | 3 | 2 |
| H 111 | DEC 9,1963 | 0833-0933 | 37-53.0S | 92-08.5W | 14.8 | 18.88 | 34.11 | 5.79 | 15.4 | 14 | 6,0 | 10 | 03 | 36 | 6 | 5 | 2 |
| H 112 | DEC 10,1963 | 0830-0945 | 36-02.1S | 93-45.9W | 15.5 | 18.98 | 34.29 | 5.64 | 15.0 | 20 | 0,6 | 10 | 03 | 20 | 7 | 7 | 3 |
| H 113 | DEC 10,1963 | 2010-2052 | 35-19.0S | 94-35.3W | 16.7 | 19.09 | 34.49 | 5.55 | 15.0 | 24 | 0,6 | 10 | 03 | 20 | 4 | 4 | 3 |
| H 114 | DEC 11,1963 | 0558-0640 | 34-17.5S | 94-32.6W | 16.8 | 19.11 | 34.52 | 5.25 | 15.0 | 26 | 6,0 | 10 | 03 | 20 | 4 | 2 | 2 |

| SURFACE OBSERVATIONS | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| STATION | DATE | TIME | LAT | LONG | SEA T (°C) | Cl (‰) | S (‰) | $O_2$ (ml/L) | AIR T (°C) | BARO (mb) | CLOUDS TYPE | CLOUDS AMOUNT | WEATHER | WIND DIR | WIND FORCE | SEA WAVES | SEA SWELL |
| H 115 | DEC 11,1963 | 2210-2254 | 33-13.6S | 94-52.7W | 17.2 | 19.23 | 34.74 | 5.39 | 16.1 | 25 | 6,0 | 10 | 03 | 25 | 3 | 2 | 2 |
| H 116 | DEC 12,1963 | 0600-0654 | 31-59.0S | 94-52.7W | 18.1 | 19.28 | 34.83 | 5.38 | 16.5 | 24 | 6,0 | 10 | 03 | 25 | 3 | 2 | 2 |
| H 117 | DEC 12,1963 | 1400-1450 | 30-28.7S | 94-48.0W | 18.7 | 19.33 | 34.92 | 5.33 | 19.0 | 23 | 6,0 | 08 | 01 | | 0 | 1 | 1 |
| H 118 | DEC 12,1963 | 2015-2100 | 29-55.8S | 94-58.5W | 19.5 | 19.50 | 35.23 | 5.20 | 17.1 | 22 | 0,6 | 06 | 01 | 18 | 2 | 1 | 2 |
| H 119 | DEC 13,1963 | 0625-0710 | 29-55.2S | 94-29.8W | 19.3 | 19.43 | 35.10 | 5.25 | 18.0 | 20 | 6,0 | 07 | 01 | 22 | 2 | 1 | 1 |
| H 120 | DEC 13,1963 | 2210-2304 | 28-37.0S | 94-55.7W | 20.2 | 19.56 | 35.34 | 5.14 | 18.0 | 20 | 5,4 | 02 | 00 | 27 | 2 | 1 | 1 |
| H 121 | DEC 14,1963 | 0600-0645 | 27-16.2S | 94-55.5W | 20.6 | 19.57 | 35.35 | 5.09 | 18.5 | 20 | 5,0 | 07 | 01 | | 0 | 1 | 1 |
| H 122 | DEC 14,1963 | 1200-1246 | 26-13.6S | 94-53.2W | 21.5 | 19.65 | 35.50 | 5.07 | 22.9 | 20 | 5 | 03 | 01 | 04 | 2 | 1 | 1 |
| H 123 | DEC 14,1963 | 1800-1845 | 25-16.0S | 94-49.0W | 21.8 | 19.68 | 35.55 | 4.97 | 20.1 | 17 | 5,0 | 01 | 00 | 02 | 3 | 1 | 1 |
| H 124 | DEC 15,1963 | 0620-0706 | 24-36.5S | 95-13.1W | 21.2 | 19.61 | 35.43 | 5.01 | 19.2 | 18 | 6,0 | 09 | 01 | 09 | 2 | 1 | 1 |
| H 125 | DEC 15,1963 | 2210-2250 | 23-30.2S | 95-02.3W | 21.3 | 19.60 | 35.41 | 4.96 | 20.1 | 20 | 4,5 | 02 | 00 | 11 | 2 | 2 | 1 |
| H 126 | DEC 16,1963 | 0600-0642 | 22-11.6S | 95-04.8W | 21.2 | 19.71 | 35.61 | 4.99 | 21.0 | 19 | 0,6 | 08 | 01 | 11 | 4 | 3 | 1 |
| H 127 | DEC 16,1963 | 1200-1238 | 21-15.8S | 95-01.9W | 21.9 | 19.87 | 35.90 | 4.97 | 21.3 | 20 | 8 | 05 | 01 | 11 | 5 | 4 | 2 |
| H 128 | DEC 16,1963 | 1800-1838 | 20-18.6S | 94-59.8W | 21.8 | 19.84 | 35.84 | 4.96 | 20.7 | 18 | 8,0 | 08 | 01 | 11 | 5 | 4 | 2 |
| H 129 | DEC 17,1963 | 0602-0658 | 19-43.0S | 95-17.0W | 21.8 | 19.89 | 35.93 | 4.89 | 20.5 | 19 | 6,0 | 10 | 03 | 09 | 5 | 4 | 2 |
| H 130 | DEC 17,1963 | 2210-2249 | 18-45.8S | 95-00.3W | 21.5 | 19.82 | 35.81 | 5.02 | 20.9 | 19 | 0,6 | 10 | 03 | 11 | 6 | 5 | 2 |
| H 131 | DEC 18,1963 | 0600-0640 | 17-29.2S | 95-00.3W | 21.7 | 19.98 | 36.09 | 4.99 | 20.5 | 17 | 0 | 10 | 03 | 11 | 5 | 4 | 2 |
| H 132 | DEC 18,1963 | 1205-1235 | 16-29.8S | 95-03.1W | 21.8 | 19.81 | 35.79 | 4.98 | 23.2 | 18 | 0 | 10 | 03 | 09 | 5 | 4 | 2 |
| H 133 | DEC 18,1963 | 1800-1835 | 15-30.8S | 95-03.2W | 22.0 | 19.88 | 35.91 | 4.93 | 20.5 | 15 | 0 | 10 | 03 | 11 | 5 | 4 | 1 |
| H 134 | DEC 19,1963 | 0553-0648 | 14-31.0S | 95-14.0W | 21.9 | 19.86 | 35.88 | 5.00 | 20.5 | 16 | 0 | 10 | 03 | 11 | 5 | 4 | 2 |
| H 135 | DEC 19,1963 | 2010-2055 | 13-45.0S | 94-59.3W | 21.7 | 19.72 | 35.62 | 5.00 | 20.5 | 16 | 0,6 | 10 | 03 | 11 | 4 | 3 | 2 |
| H 136 | DEC 20,1963 | 0600-0640 | 12-24.0S | 95-00.0W | 21.8 | 19.72 | 35.62 | 4.88 | 20.2 | 13 | 0,8 | 08 | 01 | 09 | 4 | 3 | 2 |
| H 137 | DEC 20,1963 | 1200-1237 | 11-26.7S | 95-00.7W | 22.4 | 19.71 | 35.61 | 4.95 | 22.0 | 14 | 0,8 | 06 | 01 | 11 | 4 | 3 | 1 |
| H 138 | DEC 20,1963 | 1800-1835 | 10-26.8S | 95-00.3W | 22.8 | 19.32 | 34.90 | 4.93 | 19.8 | 12 | 0 | 08 | 01 | 14 | 4 | 3 | 1 |
| H 139 | DEC 21,1963 | 0610-0653 | 9-29.7S | 94-58.3W | 23.0 | 19.58 | 35.37 | 4.85 | 21.0 | 13 | 6,0 | 09 | 01 | 14 | 2 | 2 | 1 |
| H 140 | DEC 21,1963 | 2210-2246 | 9-00.0S | 94-08.6W | 23.6 | 19.42 | 35.08 | 4.76 | 22.0 | 14 | 0,6 | 06 | 01 | 14 | 5 | 4 | 1 |
| H 141 | DEC 22,1963 | 0600-0637 | 8-01.0S | 93-12.2W | 23.4 | 19.41 | 35.07 | 4.79 | 22.0 | 14 | 5,0 | 10 | 03 | 07 | 3 | 2 | 1 |
| H 142 | DEC 22,1963 | 1400-1435 | 7-05.0S | 92-13.0W | 23.9 | 19.50 | 35.23 | 5.07 | 25.3 | 11 | 5,0 | 09 | 01 | 11 | 4 | 2 | 1 |
| H 143 | DEC 22,1963 | 2210-2245 | 6-13.0S | 91-15.0W | 23.4 | 19.61 | 35.43 | 4.82 | 22.6 | 14 | 5,6 | 10 | 03 | 11 | 5 | 4 | 1 |
| H 144 | DEC 23,1963 | 0610-0655 | 5-11.5S | 90-36.3W | 23.4 | 19.49 | 35.21 | 4.85 | 21.7 | 14 | 0,7 | 10 | 03 | 14 | 5 | 4 | 1 |
| H 145 | DEC 23,1963 | 2210-2249 | 4-31.1S | 89-51.7W | 23.5 | 19.50 | 35.23 | 4.89 | 22.0 | 14 | 4,6 | 08 | 01 | 14 | 4 | 3 | 1 |
| H 146 | DEC 24,1963 | 0600-0635 | 3-29.9S | 88-57.0W | 23.4 | 19.29 | 34.85 | 4.81 | 23.0 | 14 | 0,6 | 10 | 03 | 14 | 4 | 3 | 1 |
| H 147 | DEC 24,1963 | 1420-1510 | 2-27.5S | 88-04.0W | 24.0 | 19.19 | 34.67 | 4.60 | 25.3 | 12 | 8,0 | 07 | 01 | 18 | 4 | 3 | 1 |
| H 148 | DEC 24,1963 | 2210-2255 | 1-35.2S | 87-17.7W | 24.2 | 18.85 | 34.05 | 4.72 | 23.0 | 15 | 4,5 | 07 | 01 | 18 | 3 | 3 | 1 |
| H 149 | DEC 25,1963 | 0600-0637 | 0-33.4S | 86-24.5W | 24.8 | 18.60 | 33.60 | 4.64 | 23.5 | 12 | 5,4 | 10 | 03 | 18 | 5 | 4 | 1 |
| H 150 | DEC 25,1963 | 1420-1510 | 0-26.5N | 85-30.0W | 25.6 | 18.35 | 33.15 | 4.56 | 24.0 | 12 | 0 | 10 | 03 | 18 | 5 | 4 | 2 |
| H 151 | DEC 25,1963 | 2210-2245 | 1-23.1N | 84-42.0W | 25.2 | 18.37 | 33.19 | 4.65 | 23.7 | 13 | 5,0 | 10 | 03 | 18 | 4 | 3 | 2 |
| H 152 | DEC 26,1963 | 0600-0645 | 2-22.9N | 83-51.9W | 26.2 | 18.03 | 32.57 | 4.50 | 24.5 | 10 | | | 61 | 20 | 4 | | 1 |
| H 153 | DEC 26,1963 | 1420-1500 | 3-42.5N | 82-45.0W | 27.2 | 18.04 | 32.59 | 4.48 | 27.4 | 09 | 8 | 03 | 01 | 20 | 3 | 3 | 1 |
| H 154 | JAN 4,1964 | 1220-1325 | 5-37.4N | 81-50.6W | 28.2 | 16.54 | 29.88 | 4.66 | 28.9 | 10 | 0 | 01 | 00 | 34 | 2 | 2 | 1 |
| H 155 | JAN 4,1964 | 1600-1610 | 5-14.0N | 82-14.2W | 27.5 | 16.32 | 29.49 | 4.63 | 29.8 | 07 | 0,8 | 06 | 01 | 32 | 2 | 2 | 1 |
| H 156 | JAN 4,1964 | 2010-2023 | 4-47.5N | 82-41.8W | 27.8 | 16.29 | 29.43 | 4.80 | 26.6 | 09 | ,0 | 04 | 01 | 16 | 4 | 3 | 2 |
| H 157 | JAN 5,1964 | 0000-0015 | 4-18.9N | 83-11.4W | 27.3 | 16.35 | 29.54 | 4.56 | 27.4 | 10 | 7,0 | 10 | 03 | 16 | 3 | 3 | 2 |
| H 158 | JAN 5,1964 | 0400-0415 | 3-50.3N | 83-41.2W | 26.8 | 17.28 | 31.22 | 4.56 | 25.2 | 08 | 7,0 | 10 | 03 | 20 | 4 | 3 | 2 |
| H 159 | JAN 5,1964 | 0800-0815 | 3-23.1N | 84-10.2W | 26.4 | 18.08 | 32.66 | 4.54 | 25.0 | 10 | 5 | 04 | 01 | 20 | 4 | 3 | 2 |
| H 160 | JAN 5,1964 | 1220-1308 | 3-14.7N | 85-05.7W | 26.3 | 18.17 | 32.83 | 4.64 | 26.0 | 10 | 5 | 10 | 03 | 18 | 4 | 3 | 2 |
| H 161 | JAN 5,1964 | 1600-1610 | 2-57.0N | 85-21.2W | 26.6 | 18.28 | 33.03 | 4.61 | 27.0 | 08 | 8,0 | 09 | 01 | 18 | 4 | 3 | 2 |
| H 162 | JAN 5,1964 | 2010-2016 | 2-26.9N | 85-46.6W | 26.5 | 18.24 | 32.95 | 4.61 | 26.5 | 10 | 0,5 | 09 | 03 | 20 | 4 | 3 | 2 |
| H 163 | JAN 6,1964 | 0000-0008 | 1-55.0N | 86-13.5W | 26.3 | 18.35 | 33.15 | 4.56 | 24.0 | 11 | 5,0 | 05 | 01 | 18 | 3 | 3 | 2 |
| H 164 | JAN 6,1964 | 0400-0410 | 1-23.0N | 86-40.0W | 25.8 | 18.54 | 33.49 | 4.62 | 24.0 | 09 | | 10 | 03 | 18 | 3 | 3 | 2 |
| H 165 | JAN 6,1964 | 0800-0810 | 0-51.2N | 87-07.7W | 25.8 | 18.59 | 33.58 | 4.58 | 24.4 | 11 | 5,0 | 10 | 03 | 18 | 3 | 3 | 2 |
| H 166 | JAN 6,1964 | 1225-1313 | 0-26.3N | 87-31.6W | 25.8 | 18.68 | 33.75 | 4.60 | 26.7 | 10 | 8 | 02 | 01 | 18 | 3 | 3 | 2 |
| H 167 | JAN 6,1964 | 1600-1610 | 0-01.5N | 87-52.0W | 25.4 | 18.71 | 33.80 | 4.67 | 26.5 | 07 | 8,5 | 01 | 00 | 18 | 4 | 3 | 2 |
| H 168 | JAN 6,1964 | 2010-2018 | 0-25.5S | 88-28.9W | 24.4 | 18.81 | 33.98 | 4.76 | 23.5 | 08 | 5 | 02 | 00 | 18 | 4 | 3 | 2 |
| H 169 | JAN 7,1964 | 0000-0011 | 1-02.6S | 88-50.0W | 23.6 | 19.17 | 34.63 | 4.73 | 23.3 | 10 | 5 | 04 | 01 | 18 | 4 | 3 | 2 |
| H 170 | JAN 7,1964 | 0400-0410 | 1-39.0S | 89-10.5W | 23.6 | 19.19 | 34.67 | 4.71 | 23.0 | 09 | 5,0 | 10 | 03 | 18 | 4 | 3 | 2 |
| H 171 | JAN 7,1964 | 0800-0807 | 2-07.2S | 89-41.5W | 23.6 | 19.21 | 34.70 | 4.68 | 23.0 | 11 | 5,0 | 10 | 03 | 18 | 4 | 3 | 2 |

SURFACE OBSERVATIONS

| STATION | DATE | TIME | LAT | LONG | SEA T | CI | S | $O_2$ | AIR T | BARO | CLOUDS |  | WEATHER | WIND |  | SEA |  |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
|  |  |  |  |  | (°C) | (‰) | (‰) | (ml/L) | (°C) | (mb) | TYPE | AMOUNT |  | DIR | FORCE | WAVES | SWELL |
| H 172 | JAN 7,1964 | 1220-1304 | 2-38.8S | 90-13.2W | 24.0 | 19.26 | 34.79 | 4.72 | 23.9 | 10 | 5,0 | 05 | 01 | 18 | 3 | 2 | 1 |
| H 173 | JAN 7,1964 | 1600-1608 | 2-59.0S | 90-39.0W | 24.0 | 19.28 | 34.83 | 4.82 | 23.5 | 07 | 4,0 | 08 | 01 | 18 | 3 | 2 | 1 |
| H 174 | JAN 7,1964 | 2010-2017 | 3-25.1S | 91-15.5W | 23.8 | 19.27 | 34.81 | 4.80 | 23.6 | 08 | 5 | 03 | 00 | 18 | 4 | 3 | 1 |
| H 175 | JAN 8,1964 | 0000-0012 | 3-52.8S | 91-47.9W | 23.7 | 19.26 | 34.79 |  | 23.0 | 10 | 5 | 05 | 01 | 16 | 4 | 3 | 2 |
| H 176 | JAN 8,1964 | 0400-0410 | 4-18.2S | 92-19.2W | 23.8 | 19.30 | 34.87 | 4.81 | 23.0 | 08 | 5,0 | 10 | 03 | 14 | 4 | 3 | 2 |
| H 177 | JAN 8,1964 | 0800-0807 | 4-44.2S | 92-50.2W | 23.8 | 19.34 | 34.94 | 4.86 | 23.1 | 12 | 0,5 | 10 | 03 | 14 | 4 | 3 | 2 |
| H 178 | JAN 8,1964 | 1225-1308 | 5-11.6S | 93-23.0W | 24.1 | 19.17 | 34.63 | 4.87 | 23.5 | 10 | 0 | 10 | 03 | 14 | 4 | 3 | 2 |
| H 179 | JAN 8,1964 | 1600-1608 | 5-34.5S | 94-00.0W | 23.8 | 19.28 | 34.83 | 4.88 | 25.0 | 08 | 0 | 10 | 03 | 14 | 4 | 3 | 2 |
| H 180 | JAN 8,1964 | 2010-2018 | 6-01.1S | 94-32.1W | 23.8 | 19.39 | 35.03 | 4.81 | 23.4 | 11 | 5,0 | 10 | 03 | 14 | 4 | 3 | 2 |
| H 181 | JAN 9,1964 | 0000-0008 | 6-23.7S | 95-04.9W | 23.8 | 19.32 | 34.90 | 4.82 | 22.9 | 12 | 5,0 | 09 | 03 | 16 | 5 | 4 | 3 |
| H 182 | JAN 9,1964 | 0400-0408 | 6-55.5S | 95-37.5W | 23.6 | 19.32 | 34.90 | 4.83 | 22.6 | 10 | 0,5 | 10 | 03 | 14 | 5 | 4 | 3 |
| H 183 | JAN 9,1964 | 0800-0807 | 7-22.0S | 96-09.2W | 23.8 | 19.39 | 35.03 | 4.85 | 23.6 | 14 | 0,5 | 10 | 03 | 14 | 5 | 4 | 2 |
| H 184 | JAN 9,1964 | 1220-1306 | 7-44.8S | 96-52.9W | 23.7 | 19.50 | 35.23 | 4.90 | 23.7 | 14 | 5 | 07 | 01 | 14 | 5 | 4 | 2 |
| H 185 | JAN 9,1964 | 1600-1608 | 8-05.2S | 97-19.0W | 23.6 | 19.60 | 35.41 | 4.84 | 25.4 | 11 | 5,0 | 04 | 01 | 11 | 5 | 4 | 2 |
| H 186 | JAN 9,1964 | 2010-2018 | 8-31.9S | 97-54.2W | 23.3 | 19.65 | 35.50 | 4.85 | 22.6 | 13 | 5 | 02 | 00 | 14 | 4 | 3 | 2 |
| H 187 | JAN 10,1964 | 0400-0410 | 9-00.5S | 98-29.0W | 22.9 | 19.63 | 35.46 | 4.87 | 21.3 | 12 | 0 | 04 | 01 | 14 | 4 | 3 | 2 |
| H 188 | JAN 10,1964 | 0800-0807 | 9-26.9S | 98-49.9W | 22.9 | 19.68 | 35.55 | 4.89 | 22.5 | 14 | 5 | 05 | 01 | 14 | 5 | 4 | 2 |
| H 189 | JAN 10,1964 | 1220-1310 | 9-56.8S | 99-46.7W | 23.2 | 19.70 | 35.59 | 4.97 | 23.5 | 14 | 5 | 02 | 00 | 14 | 4 | 3 | 2 |
| H 190 | JAN 11,1964 | 0620-0700 | 9-31.9S | 100-12.4W | 23.0 | 19.72 | 35.62 | 4.91 | 22.0 | 12 | 5,0 | 10 | 03 | 10 | 4 | 3 | 2 |
| H 191 | JAN 11,1964 | 1600-1608 | 9-35.5S | 100-02.0W | 23.4 | 19.71 | 35.61 | 4.89 | 22.8 | 11 | 0 | 09 | 01 | 11 | 3 | 3 | 2 |
| H 192 | JAN 11,1964 | 2010-2020 | 8-53.0S | 100-07.2W | 23.4 | 19.67 | 35.53 | 4.88 | 21.5 | 12 | 4,5 | 01 | 00 | 11 | 3 | 3 | 2 |
| H 193 | JAN 12,1964 | 0000-0007 | 8-13.0S | 100-13.0W | 23.5 | 19.57 | 35.35 | 4.90 | 22.1 | 14 | 5,0 | 05 | 01 | 11 | 4 | 3 | 2 |
| H 194 | JAN 12,1964 | 0400-0408 | 7-30.5S | 100-19.0W | 23.8 | 19.51 | 35.25 | 4.81 | 22.6 | 12 | 0 | 09 | 01 | 16 | 4 | 3 | 2 |
| H 195 | JAN 12,1964 | 0800-0843 | 6-48.0S | 100-24.9W | 24.1 |  |  | 4.83 | 23.0 | 14 | 0,5 | 10 | 03 | 11 | 4 | 3 | 2 |
| H 196 | JAN 12,1964 | 1240-1300 | 6-09.4S | 100-29.4W | 24.1 | 19.31 | 34.88 | 4.84 | 24.9 | 13 | 0,5 | 10 | 03 | 11 | 4 | 3 | 2 |
| H 197 | JAN 12,1964 | 1600-1609 | 5-38.0S | 100-31.0W | 24.2 | 19.30 | 34.87 | 4.83 | 24.0 | 10 | 0 | 10 | 03 | 14 | 4 | 3 | 2 |
| H 198 | JAN 13,1964 | 0630-0700 | 5-10.4S | 100-49.8W | 24.2 | 19.31 | 34.88 | 4.81 | 23.0 | 12 | 5,0 | 10 | 03 | 14 | 5 | 4 | 2 |
| H 199 | JAN 13,1964 | 2002-2033 | 4-41.2S | 100-48.8W | 24.4 | 19.28 | 34.83 | 4.73 | 23.5 | 12 | 5,0 | 10 | 03 | 11 | 4 | 4 | 2 |
| H 200 | JAN 14,1964 | 0000-0013 | 4-00.6S | 100-54.3W | 24.1 | 19.31 | 34.88 | 4.68 | 22.5 | 13 | 0 | 10 | 03 | 11 | 4 | 4 | 2 |
| H 201 | JAN 14,1964 | 0400-0407 | 3-20.0S | 101-00.0W | 23.9 | 19.31 | 34.88 | 4.58 | 23.8 | 10 | 0 | 10 | 03 | 11 | 5 | 4 | 2 |
| H 202 | JAN 14,1964 | 0803-0850 | 2-37.5S | 101-06.2W | 24.3 | 19.18 | 34.65 | 4.53 | 24.3 | 12 | 5,0 | 10 | 03 | 10 | 4 | 3 | 2 |
| H 203 | JAN 14,1964 | 1220-1240 | 2-02.3S | 101-17.7W | 24.4 | 19.16 | 34.61 | 4.44 | 24.5 | 12 | 5,0 | 07 | 01 | 14 | 3 | 3 | 2 |
| H 204 | JAN 14,1964 | 1600-1609 | 1-25.5S | 101-23.0W | 24.6 | 19.15 | 34.60 | 4.44 | 24.5 | 09 | 5,8 | 05 | 01 | 14 | 4 | 3 | 2 |
| H 205 | JAN 15,1964 | 0559-0715 | 0-50.4S | 101-40.5W | 24.6 | 19.10 | 34.51 | 4.69 | 23.8 | 10 | 5,0 | 10 | 03 | 14 | 3 | 2 | 1 |
| H 206 | JAN 15,1964 | 2010-2020 | 0-16.8S | 101-48.3W | 24.8 | 19.05 | 34.42 | 4.66 | 24.0 | 10 | 5,8 | 06 | 01 | 14 | 3 | 3 | 1 |
| H 207 | JAN 16,1964 | 0000-0008 | 0-23.1N | 101-48.3W | 24.9 | 19.03 | 34.38 | 4.56 | 23.5 | 10 | 0,5 | 05 | 01 | 14 | 4 | 3 | 1 |
| H 208 | JAN 16,1964 | 0400-0410 | 1-05.4N | 101-48.2W | 24.9 | 18.95 | 34.23 | 4.73 | 23.6 | 10 | 0 | 09 | 01 | 14 | 4 | 3 | 1 |
| H 209 | JAN 16,1964 | 0800-0900 | 1-47.9N | 101-48.3W | 25.0 | 19.05 | 34.42 | 4.64 | 24.8 | 12 | 5,0 | 06 | 01 | 14 | 4 | 3 | 1 |
| H 210 | JAN 16,1964 | 1200-1235 | 2-25.8N | 102-10.8W | 25.5 | 19.07 | 34.45 | 4.75 | 28.0 | 11 | 5,0 | 05 | 01 | 16 | 4 | 3 | 2 |
| H 211 | JAN 16,1964 | 1600-1610 | 2-52.5N | 101-47.0W | 26.1 | 18.95 | 34.23 | 4.57 | 25.5 | 08 | 5,0 | 08 | 01 | 16 | 4 | 3 | 2 |
| H 212 | JAN 17,1964 | 0625 | 3-26.0N | 101-49.2W | 26.3 | 18.93 | 34.20 | 4.52 |  | 10 | 5,0 | 09 | 01 | 18 | 4 | 3 | 2 |
| H 213 | JAN 17,1964 | 2000-2015 | 4-01.7N | 102-05.7W | 26.5 | 18.90 | 34.14 | 4.50 | 24.2 | 12 | 5,4 | 06 | 01 | 18 | 2 | 2 | 1 |
| H 214 | JAN 18,1964 | 0000-0010 | 4-41.4N | 102-05.7W | 26.5 | 18.87 | 34.09 |  | 24.4 | 12 | 0 | 10 | 03 | 16 | 2 | 2 | 1 |
| H 215 | JAN 18,1964 | 0400-0410 | 5-22.0N | 102-05.7W | 27.0 | 18.94 | 34.22 | 4.56 | 24.9 | 10 | 0 | 09 | 01 | 20 | 3 | 2 | 1 |
| H 216 | JAN 18,1964 | 0800-0852 | 6-03.2N | 102-05.7W | 27.2 | 18.84 | 34.04 | 4.40 | 22.5 | 12 | 7,0 | 08 | 01 | 20 | 3 | 3 | 2 |
| H 217 | JAN 18,1964 | 1225-1235 | 6-36.6N | 102-05.7W | 26.9 | 18.81 | 33.98 | 4.53 | 25.5 | 12 | 0 | 10 | 03 | 11 | 5 | 3 | 2 |
| H 218 | JAN 18,1964 | 1600-1609 | 7-17.0N | 102-00.5W | 27.2 | 18.84 | 34.04 | 4.61 | 25.8 | 09 | 5,8 | 06 | 01 | 07 | 4 | 4 | 2 |
| H 219 | JAN 19,1964 | 0620-0710 | 7-49.4N | 102-45.4W | 27.0 |  |  | 4.45 | 26.4 | 12 | 8,0 | 05 | 01 | 07 | 5 | 4 | 2 |
| H 220 | JAN 19,1964 | 2002-2022 | 8-33.3N | 102-27.2W | 27.0 | 18.55 | 33.51 | 4.55 | 25.2 | 12 | 8 | 03 | 01 | 04 | 5 | 4 | 2 |
| H 221 | JAN 20,1964 | 0002-0013 | 9-21.3N | 102-27.6W | 26.9 | 18.68 | 33.75 | 4.51 | 25.8 | 12 | 5,0 | 03 | 00 | 07 | 5 | 4 | 3 |
| H 222 | JAN 20,1964 | 0400-0416 | 9-53.7N | 102-39.0W | 26.2 | 18.59 | 33.58 | 4.65 | 25.5 | 11 | 8 | 02 | 01 | 07 | 4 | 3 | 2 |
| H 223 | JAN 20,1964 | 0803 | 10-32.3N | 102-47.6W | 27.4 |  |  | 4.47 | 26.9 | 13 | 8 | 03 | 01 | 04 | 4 | 2 | 1 |
| H 224 | JAN 20,1964 | 1200-1230 | 11-01.9N | 102-53.4W | 27.7 | 18.75 | 33.87 | 4.62 | 28.0 | 12 | 5,8 | 04 | 00 | 07 | 3 | 2 | 1 |
| H 225 | JAN 20,1964 | 1600-1605 | 11-40.8N | 102-57.9W | 27.7 | 18.65 | 33.69 | 4.47 | 27.0 | 10 | 5,8 | 04 | 01 | 02 | 3 | 2 | 1 |
| H 226 | JAN 21,1964 | 0618-0713 | 12-40.0N | 103-27.8W | 27.5 | 18.28 | 33.03 | 4.46 | 26.3 | 13 | 5,8 | 05 | 01 | 02 | 3 | 2 | 1 |
| H 227 | JAN 21,1964 | 2001-2021 | 13-00.9N | 103-32.4W | 26.9 | 18.50 | 33.42 | 4.52 | 26.5 | 11 | 5,8 | 02 | 01 | 04 | 4 | 2 | 1 |
| H 228 | JAN 22,1964 | 0000-0009 | 13-28.7N | 103-37.8W | 27.3 | 18.65 | 33.69 | 4.42 | 26.2 | 12 | 5,8 | 04 | 01 | 04 | 3 | 3 | 1 |

| | | | | | SURFACE OBSERVATIONS | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| STATION | DATE | TIME | LAT | LONG | SEA T (°C) | Cl (‰) | S (‰) | $O_2$ (ml/L) | AIR T (°C) | BARO (mb) | CLOUDS TYPE | CLOUDS AMOUNT | WEATHER | WIND DIR | WIND FORCE | SEA WAVES | SEA SWELL |
| H 229 | JAN 22,1964 | 0400-0412 | 14-08.0N | 103-45.0W | 27.5 | 18.75 | 33.87 | 4.46 | 26.0 | 12 | 8 | 02 | 01 | 34 | 3 | 2 | 1 |
| H 230 | JAN 22,1964 | 0806-0910 | 14-58.5N | 103-49.1W | 27.5 | | | 4.46 | 26.5 | 14 | 8 | 04 | 01 | 32 | 3 | 2 | 1 |
| H 231 | JAN 22,1964 | 1200-1210 | 15-30.2N | 103-55.3W | 27.7 | 18.67 | 33.73 | | 26.0 | 15 | 5,8 | 03 | 00 | 32 | 2 | 1 | 1 |
| H 232 | JAN 31,1964 | 0800-0815 | 16-49.9N | 106-46.9W | 26.2 | 18.65 | 33.69 | 4.52 | 25.3 | 13 | 5,0 | 07 | 01 | 36 | 3 | 3 | 2 |
| H 233 | JAN 31,1964 | 1225-1235 | 16-17.7N | 107-20.7W | 26.8 | 18.55 | 33.51 | 4.50 | 26.8 | 14 | 0,5 | 09 | 03 | 36 | 4 | 3 | 2 |
| H 234 | JAN 31,1964 | 1600-1611 | 15-52.3N | 107-49.0W | 27.2 | 18.65 | 33.69 | 4.52 | 25.8 | 12 | 0,5 | 10 | 03 | 36 | 4 | 3 | 2 |
| H 235 | JAN 31,1964 | 2015-2115 | 15-24.0N | 108-19.5W | 26.9 | 18.44 | 33.31 | 4.41 | 25.3 | 14 | 0,8 | 10 | 03 | 36 | 4 | 3 | 2 |
| H 236 | FEB 1,1964 | 0000-0012 | 15-01.3N | 108-46.4W | 26.7 | 18.50 | 33.42 | 4.60 | 25.6 | 13 | 0 | 10 | 03 | 04 | 5 | 4 | 3 |
| H 237 | FEB 1,1964 | 0625-0637 | 14-30.0N | 109-44.6W | 26.8 | 18.45 | 33.33 | 4.56 | 26.0 | 12 | 0 | 10 | 51 | 04 | 5 | 4 | 3 |
| H 238 | FEB 1,1964 | 2015-2108 | 14-01.5N | 109-54.8W | 26.8 | 18.33 | 33.12 | 4.59 | 26.0 | 13 | 0 | 10 | 03 | 04 | 3 | 3 | 2 |
| H 239 | FEB 2,1964 | 0000-0009 | 13-37.0N | 110-22.9W | 26.6 | 18.40 | 33.24 | 4.59 | 26.1 | 12 | 4,5 | 04 | 01 | 04 | 4 | 3 | 2 |
| H 240 | FEB 2,1964 | 0400-0410 | 13-08.8N | 110-54.3W | 26.5 | 18.32 | 33.10 | 4.55 | 25.5 | 10 | 5,8 | 05 | 01 | 04 | 4 | 3 | 2 |
| H 241 | FEB 2,1964 | 0800-0811 | 12-37.9N | 111-25.8W | 26.8 | 18.38 | 33.21 | 4.62 | 26.9 | 13 | 5,8 | 07 | 01 | 07 | 4 | 3 | 2 |
| H 242 | FEB 2,1964 | 1220-1231 | 12-13.4N | 111-57.7W | 27.1 | 18.48 | 33.39 | 4.43 | 29.4 | 12 | 8,5 | 05 | 01 | 09 | 4 | 3 | 2 |
| H 243 | FEB 2,1964 | 1600-1610 | 11-45.0N | 112-23.5W | 27.0 | 18.38 | 33.21 | 4.55 | 27.4 | 10 | 8,5 | 03 | 01 | 09 | 3 | 3 | 3 |
| H 244 | FEB 2,1964 | 2015-2107 | 11-16.5N | 112-55.9W | 26.8 | 18.31 | 33.08 | 4.58 | 26.5 | 12 | 8,7 | 10 | 18 | 22 | 5 | 3 | 2 |
| H 245 | FEB 2,1964 | 2305-2312 | 11-01.4N | 113-08.6W | 26.8 | 18.35 | 33.15 | 4.59 | 25.5 | 12 | 8,7 | 04 | 01 | 04 | 3 | 3 | 2 |
| H 246 | FEB 3,1964 | 0625-0635 | 11-20.9N | 113-16.0W | 26.9 | 18.37 | 33.19 | 4.54 | 26.0 | 10 | 8,0 | 07 | 01 | 09 | 4 | 3 | 2 |
| H 247 | FEB 3,1964 | 2015-2105 | 10-29.0N | 113-58.6W | 27.1 | 18.45 | 33.33 | 4.57 | 26.5 | 11 | 0,8 | 05 | 01 | 07 | 4 | 4 | 2 |
| H 248 | FEB 4,1964 | 0000-0014 | 10-04.0N | 114-23.0W | 27.0 | 18.52 | 33.46 | 4.54 | 26.5 | 10 | 8,0 | 07 | 01 | 09 | 5 | 4 | 3 |
| H 249 | FEB 4,1964 | 0400-0409 | 9-36.0N | 114-51.0W | 27.0 | 18.68 | 33.75 | 4.59 | 26.3 | 09 | 1,5 | 08 | 01 | 09 | 5 | 4 | 4 |
| H 250 | FEB 4,1964 | 0800-0809 | 9-06.1N | 115-20.8W | 27.0 | 18.66 | 33.71 | 4.63 | 26.5 | 11 | 5,8 | 08 | 01 | 09 | 5 | 4 | 3 |
| H 251 | FEB 4,1964 | 1220-1230 | 8-40.6N | 115-58.2W | 27.2 | 18.70 | 33.78 | 4.61 | 29.3 | 10 | 5,8 | 07 | 01 | 09 | 5 | 4 | 3 |
| H 252 | FEB 4,1964 | 1600-1609 | 8-07.8N | 116-17.0W | 27.1 | 18.66 | 33.71 | 4.63 | 27.1 | 08 | 6,0 | 09 | 01 | 09 | 5 | 4 | 3 |
| H 253 | FEB 4,1964 | 2015-2101 | 7-28.9N | 116-37.0W | 27.1 | 18.71 | 33.80 | 4.62 | 27.0 | 10 | 4,5 | 07 | 01 | 07 | 4 | 4 | 3 |
| H 254 | FEB 5,1964 | 0627-0635 | 7-40.6N | 117-10.2W | 26.9 | 18.91 | 34.16 | 4.47 | 26.0 | 09 | 8,4 | 06 | 01 | 07 | 4 | 3 | 2 |
| H 255 | FEB 5,1964 | 2015-2059 | 6-55.0N | 117-27.4W | 27.2 | 19.15 | 34.60 | 4.57 | 24.4 | 09 | 0,5 | 05 | 01 | 09 | 4 | 3 | 2 |
| H 256 | FEB 6,1964 | 0000-0005 | 6-30.7N | 117-53.9W | 26.9 | 19.13 | 34.56 | 4.64 | 26.2 | 10 | 5,0 | 04 | 01 | 07 | 3 | 3 | 2 |
| H 257 | FEB 6,1964 | 0400-0410 | 6-04.0N | 118-23.0W | 26.8 | 18.99 | 34.31 | 4.58 | 24.5 | 07 | 0 | 10 | 03 | 11 | 3 | 2 | 2 |
| H 258 | FEB 6,1964 | 0800-0810 | 5-36.0N | 118-52.7W | 26.7 | 18.87 | 34.09 | 4.61 | 24.5 | 10 | 5,8 | 09 | 51 | 18 | 4 | 2 | 3 |
| H 259 | FEB 6,1964 | 1220-1230 | 5-15.7N | 119-13.2W | 27.0 | 19.02 | 34.36 | 4.59 | 25.6 | 09 | 0,7 | 10 | 03 | 16 | 3 | 3 | 2 |
| H 260 | FEB 6,1964 | 1600-1610 | 4-51.6N | 119-37.5W | 27.1 | 19.15 | 34.60 | 4.63 | 26.1 | 06 | 5,0 | 08 | 01 | 18 | 4 | 3 | 2 |
| H 261 | FEB 6,1964 | 2010-2052 | 4-17.0N | 120-00.5W | 27.0 | 19.28 | 34.83 | 4.57 | 26.0 | 08 | 0 | 10 | 01 | 16 | 5 | 4 | 2 |
| H 262 | FEB 7,1964 | 0000-0010 | 3-51.3N | 120-22.2W | 26.8 | 19.18 | 34.65 | 4.57 | 25.0 | 09 | 0 | 09 | 03 | 14 | 6 | 5 | 3 |
| H 263 | FEB 7,1964 | 0625-0635 | 4-28.5N | 120-28.2W | 26.8 | 19.20 | 34.69 | 4.59 | 25.4 | 08 | 0,7 | 08 | 01 | 16 | 4 | 3 | 2 |
| H 264 | FEB 7,1964 | 2010-2102 | 3-29.2N | 121-03.5W | 26.8 | 19.23 | 34.74 | 4.59 | 26.0 | 09 | 8,0 | 08 | 01 | 16 | 5 | 4 | 2 |
| H 265 | FEB 8,1964 | 0000-0008 | 3-04.5N | 121-26.1W | 26.8 | 19.19 | 34.67 | 4.58 | 26.5 | 09 | | 05 | 01 | 14 | 5 | 4 | 4 |
| H 266 | FEB 8,1964 | 0400-0409 | 2-34.0N | 121-53.7W | 26.2 | 19.08 | 34.47 | 4.76 | 25.0 | 08 | 8,0 | 07 | 01 | 16 | 4 | 3 | 3 |
| H 267 | FEB 8,1964 | 0800-0810 | 2-04.1N | 122-04.2W | 25.9 | 19.19 | 34.67 | 4.72 | 25.0 | 10 | 5,0 | 07 | 01 | 11 | 5 | 4 | 3 |
| H 268 | FEB 8,1964 | 1220-1230 | 1-37.7N | 123-11.0W | 26.1 | 19.17 | 34.63 | 4.76 | 27.5 | 09 | 5,0 | 07 | 01 | 14 | 5 | 4 | 3 |
| H 269 | FEB 8,1964 | 1600-1609 | 1-05.8N | 123-39.5W | 25.8 | 19.18 | 34.65 | 4.71 | 26.0 | 08 | 8,0 | 07 | 01 | 14 | 5 | 4 | 2 |
| H 270 | FEB 8,1964 | 2013-2055 | 0-27.0N | 123-59.5W | 25.6 | 19.28 | 34.83 | 4.63 | 24.8 | 10 | 5,8 | 05 | 01 | 11 | 5 | 4 | 2 |
| H 271 | FEB 9,1964 | 0630-0640 | 0-49.3N | 124-23.8W | 25.5 | 19.24 | 34.76 | 4.66 | 24.0 | 11 | 6,8 | 01 | 00 | 11 | 4 | 3 | 2 |
| H 272 | FEB 9,1964 | 2010-2057 | 0-03.8N | 124-46.0W | 25.3 | 19.36 | 34.97 | 4.56 | 24.9 | 10 | 8,6 | 03 | 01 | 11 | | 3 | 3 |
| H 273 | FEB 10,1964 | 0000-0014 | 0-23.0S | 125-09.0W | 24.9 | 19.38 | 35.01 | 4.58 | 24.5 | 12 | 5 | 02 | 00 | 11 | 4 | 3 | 2 |
| H 274 | FEB 10,1964 | 0400-0407 | 0-54.0S | 125-34.5W | 25.0 | 19.40 | 35.05 | 4.55 | 24.3 | 09 | 5 | 01 | 00 | 11 | 5 | 2 | 2 |
| H 275 | FEB 10,1964 | 0800-0805 | 1-19.8S | 126-10.9W | 25.4 | 19.45 | 35.14 | 4.67 | 25.0 | 11 | 8 | 01 | 00 | 09 | 5 | 2 | 2 |
| H 276 | FEB 10,1964 | 1225-1235 | 1-49.8S | 126-49.5W | 25.8 | 19.46 | 35.16 | 4.66 | 27.6 | 09 | 5,8 | 05 | 01 | 11 | 5 | 4 | 2 |
| H 277 | FEB 10,1964 | 1600-1610 | 2-19.0S | 127-10.0W | 25.8 | 19.40 | 35.05 | 4.72 | 25.8 | 06 | 8 | 04 | 01 | 11 | 5 | 4 | 3 |
| H 278 | FEB 10,1964 | 2095-2100 | 2-56.8S | 127-38.2W | 25.8 | 19.45 | 35.14 | 4.79 | 25.3 | 09 | 8 | 03 | 01 | 11 | 5 | 4 | 3 |
| H 279 | FEB 10,1964 | 2305-2314 | 3-14.5S | 127-52.0W | 25.8 | 19.50 | 35.23 | 4.75 | 24.8 | 11 | 8,5 | 04 | 01 | 11 | 5 | 4 | 4 |
| H 280 | FEB 11,1964 | 0556-0628 | 3-34.0S | 128-22.7W | 25.8 | 19.44 | 35.12 | 4.65 | 24.3 | 10 | 0,7 | 10 | 03 | 07 | 3 | 2 | 1 |
| H 281 | FEB 11,1964 | 2010-2053 | 4-00.3S | 128-53.5W | 25.9 | 19.44 | 35.12 | 4.66 | 25.8 | 10 | 4 | 06 | 01 | 11 | 5 | 4 | 2 |
| H 282 | FEB 12,1964 | 0000-0017 | 4-25.5S | 129-20.0W | 25.9 | 19.43 | 35.10 | 4.65 | 25.4 | 13 | 4 | 01 | 00 | 09 | 5 | 4 | 3 |
| H 283 | FEB 12,1964 | 0400-0410 | 4-54.0S | 129-49.5W | 25.9 | 19.41 | 35.07 | 4.73 | 25.0 | 10 | 0,5 | 01 | 01 | 09 | 5 | 4 | 3 |
| H 284 | FEB 12,1964 | 0800-0810 | 5-35.0S | 130-19.9W | 26.0 | 19.44 | [illegible] | 4.78 | 26.0 | 12 | 8 | 01 | 00 | 09 | 6 | 5 | 3 |
| H 285 | FEB 12,1964 | 1200-1235 | 6-08.2S | 130-49.4W | 26.5 | 19.52 | 35.26 | 4.64 | 26.1 | 10 | 8 | 01 | 00 | 09 | 6 | | 3 |

| | | | | | SURFACE OBSERVATIONS | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| STATION | DATE | TIME | LAT | LONG | SEA T (°C) | Cl (‰) | S (‰) | $O_2$ (ml/L) | AIR T (°C) | BARO (mb) | CLOUDS TYPE | CLOUDS AMOUNT | WEATHER | WIND DIR | WIND FORCE | SEA WAVES | SEA SWELL |
| H 286 | FEB 12,1964 | 1600-1644 | 6-33.3S | 131-13.5W | 26.8 | 19.65 | 35.50 | 4.55 | 26.6 | 08 | 8,0 | 06 | 01 | 09 | 6 | 5 | 3 |
| H 287 | FEB 13,1964 | 0556-0627 | 6-22.0S | 131-42.3W | 26.6 | | | 4.48 | 26.0 | 10 | 8,5 | 05 | 01 | 11 | 6 | 5 | 4 |
| H 288 | FEB 13,1964 | 2010-2111 | 7-16.6S | 132-10.3W | 26.9 | 19.77 | 35.71 | 4.55 | 26.2 | 10 | 8, | 01 | 00 | 11 | 5 | 4 | 3 |
| H 289 | FEB 14,1964 | 0000-0015 | 7-38.6S | 132-34.4W | 26.7 | 19.74 | 35.66 | 4.63 | 26.1 | 10 | 8 | 01 | 00 | 11 | 5 | 4 | 3 |
| H 291 | FEB 14,1964 | 0800-0809 | 8-38.5S | 133-39.1W | 27.0 | 19.77 | 35.71 | 4.46 | 26.8 | 11 | 8,0 | 06 | 01 | 09 | 4 | 4 | 3 |
| H 292 | FEB 14,1964 | 1220-1230 | 9-09.8S | 134-10.3W | 27.4 | 19.80 | 35.77 | 4.47 | 29.8 | 10 | 8 | 01 | 00 | 09 | 5 | 4 | 3 |
| H 293 | FEB 14,1964 | 1600-1611 | 9-35.0S | 134-39.0W | 27.5 | 19.81 | 35.79 | 4.59 | 27.0 | 08 | 8,6 | 05 | 01 | 09 | 5 | 4 | 3 |
| H 294 | FEB 14,1964 | 1910-1957 | 10-03.1S | 134-55.0W | 27.4 | 19.77 | 35.71 | 4.47 | 26.5 | 10 | 8,5 | 02 | 00 | 09 | 5 | 4 | 3 |
| H 295 | FEB 15,1964 | 0620-0628 | 9-49.8S | 135-36.5W | 27.5 | 19.78 | 35.73 | 4.52 | 26.0 | 09 | 8 | 04 | 01 | 09 | 5 | 4 | 2 |
| H 296 | FEB 15,1964 | 2010-2122 | 9-20.2S | 135-36.5W | 27.7 | 19.79 | 35.75 | 4.57 | 26.4 | 09 | 8 | 03 | 01 | 09 | 4 | 3 | 2 |
| H 297 | FEB 16,1964 | 0000-0016 | 8-55.4S | 135-55.9W | 27.2 | 19.75 | 35.68 | 4.46 | 26.2 | 09 | 8 | 02 | 00 | 09 | 4 | 3 | 2 |
| H 298 | FEB 16,1964 | 0400-0409 | 8-24.0S | 136-16.0W | 27.3 | 19.75 | 35.66 | 4.67 | 25.7 | 08 | 5,8 | 03 | 01 | 09 | 4 | 3 | 2 |
| H 299 | FEB 16,1964 | 0820-0935 | 7-49.6S | 136-42.4W | 27.3 | | | 4.47 | 27.7 | 10 | 8 | 03 | 01 | 09 | 4 | 3 | 2 |
| H 300 | FEB 16,1964 | 1200-1212 | 7-27.5S | 136-58.7W | 27.5 | 19.76 | 35.70 | 4.63 | 27.6 | 08 | 8 | 03 | 01 | 09 | 4 | 3 | 2 |
| H 301 | FEB 16,1964 | 1600-1610 | 6-54.8S | 137-22.6W | 27.8 | 19.77 | 35.71 | 4.68 | 27.0 | 06 | 8 | 03 | 01 | 09 | 4 | 3 | 2 |
| H 302 | FEB 16,1964 | 2026-2105 | 6-20.3S | 137-49.2W | 27.4 | 19.69 | 35.57 | 4.56 | 25.4 | 09 | 0,8 | 06 | 01 | 09 | 3 | 3 | 2 |
| H 303 | FEB 17,1964 | 0000-0015 | 5-54.4S | 138-07.4W | 27.1 | 19.76 | 35.70 | 4.45 | 26.5 | 08 | 0 | 06 | 00 | 09 | 4 | 3 | 2 |
| H 304 | FEB 17,1964 | 0400-0409 | 5-21.5S | 138-30.5W | 26.9 | 19.66 | 35.52 | 4.51 | 25.9 | 07 | 8 | 02 | 00 | 09 | 4 | 3 | 2 |
| H 305 | FEB 17,1964 | 0825-0905 | 4-48.5S | 139-00.0W | 26.5 | 19.54 | 35.30 | 4.58 | 27.0 | 10 | 8,0 | 04 | 01 | 09 | 4 | 3 | 2 |
| H 306 | FEB 17,1964 | 1600-1613 | 3-47.0S | 139-47.5W | 27.0 | 19.61 | 35.43 | 4.48 | 27.0 | 06 | 8 | 04 | 01 | 09 | 4 | 3 | 2 |
| H 307 | FEB 17,1964 | 2025-2106 | 3-09.7S | 140-12.0W | 27.0 | 19.65 | 35.50 | 4.52 | 26.9 | 09 | 8 | 04 | 01 | 09 | 4 | 3 | 2 |
| H 308 | FEB 18,1964 | 0000-0013 | 2-44.0S | 140-30.0W | 26.7 | 19.59 | 35.39 | 4.55 | 26.0 | 08 | 8 | 01 | 00 | 09 | 4 | 3 | 2 |
| H 309 | FEB 18,1964 | 0400-0410 | 2-11.0S | 140-53.7W | 26.4 | 19.55 | 35.32 | 4.58 | 25.4 | 07 | 0 | 03 | 01 | 09 | 4 | 3 | 2 |
| H 310 | FEB 18,1964 | 0825-0904 | 1-32.1S | 141-22.1W | 26.4 | 19.46 | 35.16 | 4.57 | 27.0 | 07 | 0,8 | 04 | 01 | 09 | 5 | 4 | 3 |
| H 311 | FEB 18,1964 | 1200-1210 | 1-03.8S | 141-41.0W | 26.4 | 19.45 | 35.14 | 4.65 | 29.0 | 08 | 8 | 03 | 01 | 09 | 5 | 4 | 3 |
| H 312 | FEB 18,1964 | 1600-1616 | 0-30.0S | 142-07.0W | 26.3 | 19.42 | 35.08 | 4.50 | 26.0 | 06 | 8 | 04 | 01 | 09 | 4 | 3 | 2 |
| H 313 | FEB 18,1964 | 2025-2107 | 0-06.8N | 142-34.6W | 26.3 | 19.47 | 35.17 | 4.17 | 25.6 | 09 | 8,0 | 04 | 01 | 09 | 4 | 3 | 2 |
| H 314 | FEB 19,1964 | 0000-0015 | 0-33.8N | 142-53.7W | 26.2 | 19.35 | 34.96 | 4.13 | 26.3 | 09 | 8 | 01 | 00 | 09 | 4 | 3 | 2 |
| H 315 | FEB 19,1964 | 0400-0408 | 1-06.5N | 143-17.0W | 26.0 | 19.35 | 34.96 | 4.20 | 25.0 | 08 | 8 | 02 | 01 | 09 | 4 | 3 | 2 |
| H 316 | FEB 19,1964 | 0825-0904 | 1-41.8N | 143-48.0W | 26.7 | 19.40 | 35.05 | 4.15 | 25.8 | 10 | 8 | 04 | 01 | 09 | 4 | 3 | 2 |
| H 317 | FEB 19,1964 | 1200-1208 | 2-10.2N | 144-13.4W | 27.0 | 19.29 | 34.85 | 4.23 | 27.0 | 09 | 8,9 | 04 | 01 | 09 | 4 | 3 | 2 |
| H 318 | FEB 19,1964 | 1600-1609 | 2-44.0N | 144-34.8W | 27.4 | 19.38 | 35.01 | 4.15 | 26.3 | 06 | 8,1 | 04 | 01 | 09 | 4 | 3 | 2 |
| H 319 | FEB 19,1964 | 2025-2104 | 3-22.8N | 144-58.2W | 27.3 | 19.32 | 34.90 | 4.38 | 25.0 | 09 | 8 | 03 | 01 | 07 | 3 | 2 | 2 |
| H 320 | FEB 20,1964 | 0000-0012 | 3-49.0N | 145-17.0W | 27.0 | 19.31 | 34.88 | 4.16 | 25.3 | 09 | 8 | 01 | 00 | 07 | 3 | 2 | 2 |
| H 321 | FEB 20,1964 | 0400-0410 | 4-22.0N | 145-40.0W | 27.1 | 19.30 | 34.87 | 4.20 | 25.9 | 09 | 8,5 | 02 | 00 | 07 | 3 | 2 | 2 |
| H 322 | FEB 20,1964 | 0825-0904 | 5-02.1N | 145-59.0W | 27.3 | 19.41 | 35.07 | 4.13 | 25.6 | 10 | 0,8 | 10 | 03 | 11 | 3 | 2 | 2 |
| H 323 | FEB 20,1964 | 1200-1211 | 5-33.0N | 146-12.0W | 27.3 | 19.31 | 34.88 | 4.18 | 25.5 | 10 | 8,9 | 08 | 01 | 09 | 4 | 3 | 2 |
| H 324 | FEB 20,1964 | 1600-1608 | 6-07.0N | 146-33.0W | 27.8 | 19.33 | 34.92 | 4.18 | 26.4 | 07 | 8,9 | 08 | 01 | 07 | 4 | 3 | 2 |
| H 325 | FEB 20,1964 | 2025-2114 | 6-43.0N | 146-49.2W | 27.5 | 19.26 | 34.79 | 4.20 | 25.5 | 10 | 8,9 | 09 | 03 | 09 | 5 | 4 | 2 |
| H 326 | FEB 21,1964 | 0000-0012 | 7-07.5N | 147-07.2W | 26.9 | 19.19 | 34.67 | 4.19 | 25.0 | 10 | 8 | 04 | 01 | 09 | 6 | 4 | 3 |
| H 327 | FEB 21,1964 | 0400-0408 | 7-40.0N | 147-28.0W | 27.0 | 19.23 | 34.74 | 4.17 | 25.5 | 09 | 8 | 01 | 00 | 09 | 5 | 5 | 3 |
| H 328 | FEB 21,1964 | 0825-0903 | 8-11.1N | 147-48.2W | 27.0 | 19.22 | 34.72 | 4.16 | 25.9 | 11 | 8,0 | 07 | 01 | 07 | 6 | 5 | 3 |
| H 329 | FEB 21,1964 | 1200-1212 | 8-34.5N | 148-04.1W | 26.9 | 19.16 | 34.61 | 4.23 | 26.8 | 11 | 5,8 | 04 | 01 | 07 | 6 | 5 | 4 |
| H 330 | FEB 21,1964 | 1600-1609 | 9-05.5N | 148-30.8W | 26.9 | 19.19 | 34.67 | 4.26 | 25.9 | 09 | 5,8 | 04 | 01 | 07 | 6 | 5 | 4 |
| H 331 | FEB 21,1964 | 2025-2104 | 9-40.5N | 148-58.0W | 26.2 | 19.06 | 34.43 | 4.34 | 25.7 | 11 | 5,8 | 06 | 01 | 07 | 6 | 5 | 4 |
| H 332 | FEB 22,1964 | 0000-0020 | 10-07.1N | 149-16.0W | 25.8 | 18.96 | 34.25 | 4.30 | 25.4 | 12 | 9,0 | 07 | 01 | 07 | 6 | 5 | 3 |
| H 333 | FEB 22,1964 | 0400-0409 | 10-36.8N | 149-36.3W | 25.3 | 18.90 | 34.14 | 4.30 | 24.9 | 10 | 8,0 | 03 | 01 | 07 | 6 | 5 | 4 |
| H 334 | FEB 22,1964 | 0825-0906 | 11-14.5N | 149-59.8W | 25.6 | 18.93 | 34.20 | 4.30 | 25.0 | 13 | 8,0 | 10 | 03 | 07 | 7 | 6 | 4 |
| H 335 | FEB 22,1964 | 1200-1211 | 11-44.5N | 150-16.8W | 25.3 | 18.92 | 34.16 | 4.37 | 25.0 | 13 | 8,0 | 08 | 01 | 07 | 7 | 6 | 4 |
| H 336 | FEB 22,1964 | 1600-1609 | 12-17.0N | 150-38.5W | 24.7 | 18.93 | 34.20 | 4.41 | 24.0 | 11 | 8,9 | 06 | 01 | 07 | 7 | 6 | 4 |
| H 337 | FEB 22,1964 | 2025-2105 | 12-50.0N | 151-01.1W | 24.7 | 19.11 | 34.52 | 4.48 | 24.0 | 13 | 0,8 | 07 | 01 | 07 | 6 | 5 | 4 |
| H 338 | FEB 23,1964 | 0000-0011 | 13-14.7N | 151-15.6W | 24.6 | 18.94 | 34.22 | 4.38 | 24.0 | 14 | 5,0 | 09 | 03 | 07 | 7 | 5 | 4 |
| H 339 | FEB 23,1964 | 0400-0410 | 13-47.0N | 151-33.8W | 24.6 | 18.96 | 34.25 | 4.37 | 23.5 | 13 | 0 | 07 | 01 | 07 | 7 | 6 | 4 |
| H 340 | FEB 23,1964 | 0800-0902 | 14-23.2N | 152-06.6W | 24.5 | 18.97 | 34.27 | 4.41 | 24.0 | 16 | 5,0 | 04 | 01 | 07 | 6 | 5 | 4 |
| H 341 | FEB 23,1964 | 1200-1212 | 14-50.7N | 152-21.3W | 24.2 | 19.06 | 34.43 | 4.47 | 24.0 | 16 | 8,0 | 05 | 01 | 07 | 6 | 5 | 4 |
| H 342 | FEB 23,1964 | 1600-1609 | 15-23.9N | 152-40.0W | 23.8 | 19.11 | 34.52 | 4.49 | 23.9 | 14 | 5,8 | 06 | 01 | 07 | 6 | 5 | 4 |
| H 343 | FEB 23,1964 | 2025 | 15-56.8N | 153-13.1W | 23.7 | 18.91 | 34.16 | 4.48 | 23.5 | 17 | 8 | 01 | 01 | 07 | 6 | 5 | 4 |
| H 344 | FEB 24,1964 | 0800-0825 | 17-2[illegible].6N | 154-21.2W | 24.1 | | | | 22.5 | 18 | 0,8 | 01 | 00 | 07 | 6 | 5 | 4 |

# APPENDIX C—APENDICE C

## BIOLOGICAL OBSERVATIONS—OBSERVACIONES BIOLOGICAS

### Explanation of table headings

### Explicación de los títulos de las tablas

| | |
|---|---|
| H 023-00 | Biological observations at hydrographic or surface stations<br>Observaciones biológicas en las estaciones hidrográficas o en la superficie |
| H 023-01<br>H 023-02 | Biological observations between stations (between H 023-00 and H 024-00)<br>Observaciones biológicas entre las estaciones (entre H 023-00 y H 024-00) |
| P —31 | Biological observations at productivity stations only<br>Observaciones biológicas en las estaciones de productividad solamente |
| Time | Local time of biological observations<br>Hora local de las observaciones biológicas |
| Lat | Latitude—Latitud |
| Long | Longitude—Longitud |
| Chlorophyll *a*, *b*, *c* (mg/m$^3$) | Chlorophyll *a*, *b* and *c* concentrations, milligrams per cubic meter of surface water<br>Concentraciones de clorofila *a*, *b* y *c*, miligramos por metro cúbico de agua de la superficie |
| Carot, CP (mSPU) | Carotene concentration assuming that the phytoplankton is predominantly Chrysophyta or Pyrrophyta, milli-Specific Plant Units<br>Concentraciones de caroteno, si se asume que el fitoplancton consiste predominantemente en Crysofita o Pyrrofita, mili-Unidades Específicas de Plantas |
| Carbon Fixation (mg/m$^3$day) | Carbon fixation, milligrams of carbon per cubic meter of surface water per day<br>Fijación del carbono, miligramos por metro cúbico de agua de la superficie por día |
| Dk | Fixation in the dark<br>Fijación en la obscuridad |
| Lt | Fixation under natural light, corrected for dark fixation<br>Fijación bajo la luz natural, corregida para la fijación en la obscuridad |
| L-t | Mean of duplicate values of light fixation<br>Media de los valores duplicados de la fijación de luz |
| Zooplankton (ml) | Zooplankton volume, milliliters per net tow<br>Volumen de zooplancton, mililitros por arrastre |
| S-S | Surface net, small organisms (<5 cm in length)<br>Red de superficie, organismos pequeños (<5 cm de longitud) |
| S-L | Surface net, large organisms (>5 cm in length)<br>Red de superficie, organismos grandes (>5 cm de longitud) |
| 20-S | 20-meter net, small organisms (<5 cm in length)<br>Red de 20 metros, organismos pequeños (<5 cm de longitud) |
| 20-L | 20-meter net, large organisms (>5 cm in length)<br>Red de 20 metros, organismos grandes (>5 cm de longitud) |

### Explanation of notes

### Explicación de las notas

a) Questionable value .042 mg/m$^3$—Valor cuestionable de .042 mg/m$^3$
b) Questionable value .143 mg/m$^3$—Valor cuestionable de .143 mg/m$^3$
c) Questionable value —.138 mg/m$^3$—Valor cuestionable de —.138 mg/m$^3$
d) Questionable value .031 mg/m$^3$—Valor cuestionable de .031 mg/m$^3$
e) Questionable value .117 mg/m$^3$—Valor cuestionable de .117 mg/m$^3$
f) Questionable value —.037 mg/m$^3$—Valor cuestionable de —.037 mg/m$^3$

BIOLOGICAL OBSERVATIONS

| STATION | DATE | TIME | LAT. | LONG. | CHLOROPHYLL *a* (mg/m³) | CHLOROPHYLL *b* (mg/m³) | CHLOROPHYLL *c* (mg/m³) | CAROT CP (mSPU) | CARBON FIXATION Dk (mg/m³-day) | CARBON FIXATION Lt (mg/m³-day) | CARBON FIXATION Lt (mg/m³-day) | CARBON FIXATION $\overline{Lt}$ (mg/m³-day) | ZOOPLANKTON S-S | ZOOPLANKTON S-L | ZOOPLANKTON 20-S | ZOOPLANKTON 20-L |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| H 001-00 | OCT 06,1963 | 1202 | 10-14N | 172-50E | | | | | | | | | 4 | 0 | | |
| H 002-00 | OCT 06,1963 | 2000 | 09-12N | 173-34E | | | | | | | | | 3 | 0 | 130 | 0 |
| H 004-00 | OCT 07,1963 | 1200 | 06-49N | 175-15E | | | | | | | | | 1 | 0 | | |
| H 005-00 | OCT 07,1963 | 2000 | 05-42N | 176-06E | | | | | | | | | 16 | 0 | 90 | 0 |
| H 008-00 | OCT 08,1963 | 2000 | 02-01N | 178-22E | | | | | | | | | 37 | 3 | 100 | 0 |
| H 010-00 | OCT 08,1963 | 1319 | 00-18S | 179-47E | | | | | | | | | 5 | 0 | 67 | 0 |
| H 011-00 | OCT 08,1963 | 2000 | 01-15S | 179-36W | | | | | | | | | 149 | 0 | 162 | 4 |
| H 013-00 | OCT 09,1963 | 1200 | 03-19S | 178-14W | | | | | | | | | 3 | 0 | 14 | 0 |
| H 014-00 | OCT 09,1963 | 2000 | 04-18S | 177-09W | | | | | | | | | 38 | 0 | 276 | 0 |
| H 016-00 | OCT 10,1963 | 1200 | 06-50S | 176-05W | | | | | | | | | 5 | 0 | 45 | 0 |
| H 017-00 | OCT 10,1963 | 2000 | 07-59S | 175-26W | | | | | | | | | 33 | 0 | 102 | 0 |
| H 019-00 | OCT 11,1963 | 1200 | 10-24S | 173-49W | | | | | | | | | 5 | 0 | 5 | 0 |
| H 020-00 | OCT 11,1963 | 2000 | 11-29S | 173-07W | | | | | | | | | 9 | 0 | 13 | 0 |
| H 022-00 | OCT 12,1963 | 1200 | 13-42S | 171-13W | | | | | | | | | 14 | 0 | 11 | 0 |
| H 023-00 | OCT 12,1963 | 1840 | 14-21S | 170-35W | | | | | | | | | | | 55 | 0 |
| H 023-01 | OCT 17,1963 | 1600 | 14-22S | 170-24W | .025 | .018 | .045 | .022 | | | | | | | | |
| H 024-00 | OCT 17,1963 | 2000 | 14-37S | 169-38W | .023 | .014 | .023 | .017 | | | | | 9 | 0 | 66 | 0 |
| H 025-01 | OCT 18,1963 | 0600 | 15-07S | 167-54W | .027 | .008 | .034 | .018 | | | | | | | | |
| H 026-00 | OCT 18,1963 | 1200 | 15-20S | 166-46W | .018 | .010 | .022 | .017 | 1.1 | 1.0 | | 1.0 | 2 | 0 | 3 | 0 |
| H 026-01 | OCT 18,1963 | 1500 | 15-25S | 166-22W | .020 | .003 | .017 | .015 | | | | | | | | |
| H 026-02 | OCT 18,1963 | 1800 | 15-27S | 165-48W | .016 | .009 | .007 | .010 | | | | | | | | |
| H 027-00 | OCT 18,1963 | 2000 | 15-29S | 165-24W | | | | | | | | | 17 | 0 | 28 | 0 |
| H 027-01 | OCT 18,1963 | 2100 | 15-29S | 165-17W | .022 | .008 | .020 | .015 | | | | | | | | |
| H 028-01 | OCT 19,1963 | 0615 | 15-36S | 163-52W | .025 | .015 | .050 | .014 | 2.7 | .8 | | .8 | | | | |
| H 028-02 | OCT 19,1963 | 0930 | 15-44S | 163-13W | .026 | .003 | .011 | .014 | | | | | | | | |
| H 029-00 | OCT 19,1963 | 1200 | 15-51S | 162-44W | .018 | .011 | .026 | .012 | 1.4 | 1.3 | | 1.3 | 2 | 0 | 7 | 0 |
| H 029-01 | OCT 19,1963 | 1600 | 15-55S | 162-21W | .020 | .007 | .028 | .012 | | | | | | | | |
| H 029-02 | OCT 19,1963 | 1800 | 15-57S | 161-54W | .020 | .010 | .025 | .014 | | | | | | | | |
| H 030-00 | OCT 19,1963 | 2000 | 16-00S | 161-27W | | | | | | | | | 180 | 6 | 38 | 0 |
| H 031-01 | OCT 20,1963 | 0530 | 16-21S | 159-48W | .023 | .010 | .026 | .014 | 2.5 | .7 | | .7 | | | | |
| H 031-02 | OCT 20,1963 | 0930 | 16-28S | 159-05W | .020 | .007 | .005 | .012 | | | | | | | | |
| H 032-00 | OCT 20,1963 | 1200 | 16-33S | 158-36W | .026 | .006 | .029 | .018 | 1.4 | 2.3 | | 2.3 | 5 | 0 | 7 | 0 |
| H 032-01 | OCT 20,1963 | 1500 | 16-02S | 158-06W | .022 | .002 | .017 | .014 | | | | | | | | |
| H 032-02 | OCT 20,1963 | 1800 | 16-38S | 157-38W | .025 | .010 | .025 | .015 | | | | | | | | |
| H 033-00 | OCT 20,1963 | 2000 | 16-42S | 157-13W | .038 | .027 | .129 | .035 | | | | | 39 | 15 | 117 | 0 |
| H 033-01 | OCT 20,1963 | 2400 | 16-48S | 156-36W | .038 | .018 | .052 | .025 | | | | | | | | |
| H 034-01 | OCT 21,1963 | 0545 | 16-53S | 155-22W | .028 | .005 | .016 | .015 | 3.7 | 1.5 | | 1.5 | | | | |
| H 034-02 | OCT 21,1963 | 0930 | 16-59S | 154-45W | .026 | .005 | .025 | .012 | | | | | | | | |
| H 035-00 | OCT 21,1963 | 1200 | 17-07S | 154-17W | .022 | .005 | .012 | .009 | 1.5 | 3.5 | | 3.5 | 1 | 0 | 6 | 0 |
| H 035-01 | OCT 21,1963 | 1500 | 17-09S | 154-09W | .039 | .014 | .033 | .018 | | | | | | | | |
| H 035-02 | OCT 21,1963 | 1800 | 17-12S | 153-24W | .034 | .008 | .017 | .017 | | | | | | | | |
| H 036-00 | OCT 21,1963 | 2000 | 17-14S | 153-01W | .036 | .015 | .034 | .019 | | | | | | | 77 | 0 |
| H 036-01 | OCT 21,1963 | 2400 | 17-15S | 152-26W | .038 | .006 | .024 | .022 | | | | | | | | |
| H 037-01 | OCT 22,1963 | 0530 | 17-20S | 151-20W | .029 | .009 | .014 | .019 | 2.3 | 3.4 | | 3.4 | | | | |
| H 037-02 | OCT 22,1963 | 0900 | 17-19S | 150-38W | .029 | .006 | .029 | .019 | | | | | | | | |
| H 038-00 | OCT 22,1963 | 1200 | 17-20S | 150-04W | .029 | .009 | .014 | .018 | 4.2 | 3.4 | | 3.4 | | | 5 | 0 |
| H 038-01 | OCT 22,1963 | 1500 | 17-25S | 149-46W | .053 | .012 | .046 | .026 | | | | | | | | |
| H 038-02 | OCT 22,1963 | 1800 | 17-32S | 149-34W | .042 | .018 | .032 | .026 | | | | | | | | |
| H 038-03 | OCT 28,1963 | 1800 | 18-00S | 148-30W | .034 | .015 | .031 | .019 | | | | | | | | |
| H 039-00 | OCT 28,1963 | 2000 | 18-15S | 148-14W | .040 | .017 | .017 | .024 | | | | | 8 | 0 | | |
| H 040-01 | OCT 29,1963 | 0530 | 19-05S | 147-00W | .022 | .008 | .020 | .01[illegible] | 3.4 | 4.[illegible] | | 4.[illegible] | | | | |
| H 040-02 | OCT 29,1963 | 0900 | 19-23S | 146-29W | .022 | .006 | .014 | .01[illegible] | | | | | | | | |
| H 041-00 | OCT 29,1963 | 1200 | 19-40S | 146-04W | .025 | .009 | .034 | .015 | 1.0 | 2.6 | | 2.[illegible] | | | | |
| H 041-01 | OCT 29,1963 | 1500 | 19-53S | 145-45W | .023 | .010 | .026 | .013 | | | | | | | | |

BIOLOGICAL OBSERVATIONS

| | | | | | CHLOROPHYLL | | | CAROT | CARBON FIXATION | | | | ZOOPLANKTON | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| STATION | DATE | TIME | LAT. | LONG. | *a* | *b* | *c* | CP | Dk | Lt | Lt | $\overline{\text{Lt}}$ | S-S | S-L | 20-S | 20-L |
| | | | | | ($\mathrm{mg/m^3}$) | | | (mSPU) | ($\mathrm{mg/m^3}$-day) | | | | | | | |
| H 041-02 | OCT 29,1963 | 1800 | 20-40S | 145-22W | .029 | .009 | .014 | .011 | | | | | | | | |
| H 042-00 | OCT 29,1963 | 2000 | 20-18S | 145-04W | .020 | .003 | .017 | .011 | | | | | 9 | 0 | | |
| H 042-01 | OCT 29,1963 | 2400 | 20-38S | 144-32W | .031 | .014 | .017 | .013 | | | | | | | | |
| H 043-01 | OCT 30,1963 | 0530 | 21-05S | 143-46W | .025 | .011 | .029 | .014 | 2.2 | 1.6 | | 1.6 | | | | |
| H 043-02 | OCT 30,1963 | 0900 | 21-26S | 143-14W | .028 | .004 | .025 | .013 | | | | | | | | |
| H 044-00 | OCT 30,1963 | 1200 | 21-44S | 142-46W | .026 | .009 | .014 | .012 | .9 | 2.3 | | 2.3 | | | | |
| H 044-01 | OCT 30,1963 | 1500 | 22-00S | 142-20W | .019 | .003 | .016 | .009 | | | | | | | | |
| H 044-02 | OCT 30,1963 | 1800 | 22-17S | 141-53W | .023 | .001 | .015 | .012 | | | | | | | | |
| H 045-00 | OCT 30,1963 | 2000 | 22-29S | 141-33W | .020 | .007 | .028 | .010 | | | | | 5 | 0 | | |
| H 045-01 | OCT 30,1963 | 2400 | 22-49S | 141-01W | .020 | .009 | .010 | .011 | | | | | | | | |
| H 046-01 | OCT 31,1963 | 0530 | 23-18S | 140-11W | .020 | .007 | .028 | .011 | 2.2 | 1.5 | | 1.5 | | | | |
| H 046-02 | OCT 31,1963 | 0930 | 23-39S | 139-33W | .019 | .008 | .020 | .008 | | | | | | | | |
| H 047-00 | OCT 31,1963 | 1200 | 23-54S | 139-09W | .019 | .003 | .016 | .012 | 1.8 | 1.8 | | 1.8 | | | | |
| H 047-01 | OCT 31,1963 | 1500 | 24-07S | 138-47W | .019 | .008 | .020 | .009 | | | | | | | | |
| H 047-02 | OCT 31,1963 | 1800 | 24-22S | 138-21W | .019 | .002 | .025 | .010 | | | | | | | | |
| H 048-00 | OCT 31,1963 | 2000 | 24-33S | 138-03W | .016 | .002 | .012 | .007 | | | | | 4 | 0 | | |
| H 048-01 | OCT 31,1963 | 2400 | 24-52S | 137-30W | .018 | .014 | .032 | .011 | | | | | | | | |
| H 048-02 | NOV 01,1963 | 0515 | 25-04S | 136-57W | .020 | .004 | .008 | .010 | 2.3 | 1.9 | | 1.9 | | | | |
| H 049-01 | NOV 01,1963 | 1200 | 25-01S | 137-00W | .031 | .017 | .024 | .020 | 3.1 | .7 | | .7 | | | | |
| H 049-02 | NOV 01,1963 | 1815 | 25-24S | 136-37W | .022 | .011 | .027 | .012 | | | | | | | | |
| H 050-00 | NOV 01,1963 | 2000 | 25-35S | 136-19W | .020 | .007 | .028 | .011 | | | | | 5 | 0 | | |
| H 050-01 | NOV 01,1963 | 2400 | 25-55S | 135-47W | .026 | .006 | .028 | .015 | | | | | | | | |
| H 051-01 | NOV 02,1963 | 0600 | 26-26S | 134-52W | .022 | .007 | .018 | .014 | 1.3 | 1.7 | | 1.7 | | | | |
| H 051-02 | NOV 02,1963 | 0900 | 26-42S | 134-26W | .028 | .004 | .025 | .014 | | | | | | | | |
| H 052-00 | NOV 02,1963 | 1200 | 26-59S | 133-56W | .024 | .012 | .030 | .016 | .8 | 2.0 | | 2.0 | | | | |
| H 052-01 | NOV 02,1963 | 1500 | 27-15S | 133-35W | .032 | .018 | .039 | .019 | | | | | | | | |
| H 052-02 | NOV 02,1963 | 1815 | 27-25S | 133-14W | .029 | .007 | .021 | .013 | | | | | | | | |
| H 053-00 | NOV 02,1963 | 2000 | 27-31S | 133-00W | .022 | .008 | .020 | .012 | | | | | 10 | 0 | | |
| H 053-01 | NOV 02,1963 | 2400 | 27-44S | 132-38W | .027 | .013 | .034 | .016 | | | | | | | | |
| H 053-02 | NOV 03,1963 | 0515 | 28-10S | 132-08W | .020 | .008 | .019 | .010 | 1.3 | 1.3 | 1.6 | 1.5 | | | | |
| H 054-01 | NOV 03,1963 | 1200 | 28-29S | 132-02W | .030 | .013 | .047 | .019 | 1.7 | .9 | 4.3 | 2.6 | | | | |
| H 054-02 | NOV 03,1963 | 1815 | 28-50S | 131-24W | .030 | .012 | .065 | .031 | | | | | | | | |
| H 055-00 | NOV 03,1963 | 2000 | 29-01S | 131-04W | .028 | .001 | .027 | .014 | | | | | 16 | 0 | | |
| H 055-01 | NOV 03,1963 | 2400 | 29-18S | 130-32W | .031 | .011 | .033 | .015 | | | | | | | | |
| H 056-01 | NOV 04,1963 | 0530 | 29-45S | 129-39W | .028 | .019 | .040 | .023 | 1.6 | 1.5 | 1.5 | 1.5 | | | | |
| H 056-02 | NOV 04,1963 | 0900 | 30-07S | 129-04W | .022 | .013 | .008 | .009 | | | | | | | | |
| H 057-00 | NOV 04,1963 | 1200 | 30-29S | 128-31W | .013 | .005 | .000 | .005 | .5 | 1.0 | 1.0 | 1.0 | | | | |
| H 057-01 | NOV 04,1963 | 1500 | 30-39S | 128-04W | .015 | .006 | .010 | .007 | | | | | | | | |
| H 057-02 | NOV 04,1963 | 1815 | 30-53S | 127-35W | .024 | .008 | .010 | .003 | | | | | | | | |
| H 058-00 | NOV 04,1963 | 2000 | 31-02S | 127-15W | .018 | .008 | .006 | .009 | | | | | 10 | 0 | | |
| H 058-01 | NOV 05,1963 | 0515 | 30-57S | 127-04W | .022 | .008 | .022 | .011 | 1.7 | 1.8 | 1.4 | 1.6 | | | | |
| H 059-01 | NOV 05,1963 | 1200 | 30-58S | 127-02W | .023 | .013 | .032 | .023 | 1.2 | .6 | .3 | .5 | | | | |
| H 060-00 | NOV 05,1963 | 2000 | 31-14S | 127-12W | .022 | .008 | .030 | .014 | | | | | 2 | 0 | | |
| H 060-01 | NOV 05,1963 | 2400 | 31-27S | 127-06W | .023 | .009 | .044 | .017 | | | | | | | | |
| H 061-01 | NOV 06,1963 | 0515 | 31-47S | 126-58W | .024 | .006 | .037 | .013 | 1.0 | .3 | .9 | .6 | | | | |
| H 062-00 | NOV 06,1963 | 1200 | 32-25S | 126-09W | .019 | .004 | .028 | .009 | .8 | .2 | .3 | .3 | | | | |
| H 062-01 | NOV 06,1963 | 1500 | 32-30S | 125-49W | .016 | .008 | .016 | .009 | | | | | | | | |
| H 062-02 | NOV 06,1963 | 1830 | 32-35S | 125-17W | .022 | .008 | .029 | .012 | | | | | | | | |
| H 063-00 | NOV 06,1963 | 2000 | 32-38S | 125-01W | .022 | .006 | .048 | .013 | | | | | 5 | 2 | | |
| H 063-01 | NOV 06,1963 | 2400 | 32-41S | 124-08W | .023 | .014 | .046 | .013 | | | | | | | | |
| H 063-02 | NOV 07,1963 | 0515 | 32-47S | 123-20W | .015 | .006 | .010 | .008 | .9 | .4 | .3 | .3 | | | | |
| H 064-01 | NOV 07,1963 | 1215 | 32-51S | 123-27W | .024 | .004 | .022 | .019 | .9 | .1 | .2 | .2 | | | | |
| H 064-02 | NOV 07,1963 | 1830 | 33-10S | 122-30W | .027 | .014 | .037 | .000 | | | | | | | | |
| H 065-00 | NOV 07,1963 | 2000 | 33-22S | 122-44W | .020 | .006 | .015 | .011 | | | | | 5 | 1 | | |

BIOLOGICAL OBSERVATIONS

| | | | | | CHLOROPHYLL | | | CAROT | CARBON FIXATION | | | | ZOOPLANKTON | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| STATION | DATE | TIME | LAT. | LONG. | *a* | *b* | *c* | CP | Dk | Lt | Lt | $\overline{\text{Lt}}$ | S-S | S-L | 20-S | 20-L |
| | | | | | (mg/m$^3$) | | | (mSPU) | (mg/m$^3$-day) | | | | | | | |
| H 065-01 | NOV 07,1963 | 2400 | 33-42S | 122-02W | .016 | .005 | .010 | .008 | | | | | | | | |
| H 066-01 | NOV 08,1963 | 0500 | 34-07S | 121-11W | .022 | .011 | .027 | .013 | .6 | .7 | .6 | .6 | | | | |
| H 066-02 | NOV 08,1963 | 0900 | 34-28S | 120-28W | .022 | .005 | .023 | .013 | | | | | | | | |
| H 067-00 | NOV 08,1963 | 1200 | 34-46S | 119-52W | .018 | .010 | .022 | .011 | .5 | .5 | .7 | .6 | | | | |
| H 067-01 | NOV 08,1963 | 1500 | 34-57S | 119-26W | .020 | .012 | .027 | .012 | | | | | | | | |
| H 067-02 | NOV 08,1963 | 1830 | 35-14S | 119-05W | .024 | .004 | .022 | .012 | | | | | | | | |
| H 068-00 | NOV 08,1963 | 2000 | 35-22S | 118-33W | | | | | | | | | 40 | 3 | | |
| H 068-01 | NOV 08,1963 | 2400 | 35-42S | 117-51W | .023 | .009 | .044 | .013 | | | | | | | | |
| H 068-02 | NOV 09,1963 | 0500 | 35-55S | 116-53W | .022 | .008 | .020 | .010 | 1.0 | 2.3 | 2.5 | 2.4 | | | | |
| H 069-01 | NOV 09,1963 | 1200 | 35-55S | 116-53W | .030 | .015 | .030 | .017 | .7 | 2.8 | 2.7 | 2.7 | | | | |
| H 069-02 | NOV 09,1963 | 1830 | 36-22S | 116-20W | .034 | .008 | .036 | .016 | | | | | | | | |
| H 070-00 | NOV 09,1963 | 2000 | 36-37S | 116-02W | .042 | .010 | .047 | .016 | | | | | 72 | 0 | | |
| H 070-01 | NOV 09,1963 | 2400 | 36-59S | 115-24W | .044 | .021 | .052 | .019 | | | | | | | | |
| H 070-02 | NOV 10,1963 | 0500 | 37-11S | 114-41W | .054 | .023 | .062 | .024 | .9 | 2.9 | 2.9 | 2.9 | | | | |
| H 071-01 | NOV 10,1963 | 1200 | 37-11S | 114-41W | .062 | a) | b) | c) | 1.0 | 1.2 | 1.3 | 1.2 | | | | |
| H 071-02 | NOV 10,1963 | 1830 | 37-23S | 114-25W | .038 | .009 | .042 | .025 | | | | | | | | |
| H 072-00 | NOV 10,1963 | 2010 | 37-26S | 114-20W | | | | | | | | | 74 | 12 | | |
| H 072-01 | NOV 10,1963 | 2400 | 37-47S | 113-43W | .031 | .010 | .029 | .019 | | | | | | | | |
| H 073-01 | NOV 11,1963 | 0900 | 38-47S | 112-01W | .044 | .014 | .045 | .014 | | | | | | | | |
| H 074-00 | NOV 11,1963 | 1200 | 39-13S | 111-23W | .051 | .019 | .052 | .017 | .7 | 3.7 | 3.5 | 3.6 | | | | |
| H 074-01 | NOV 11,1963 | 1500 | 39-25S | 110-52W | .058 | .016 | .049 | .020 | | | | | | | | |
| H 074-02 | NOV 11,1963 | 1845 | 39-49S | 110-08W | .049 | .017 | .055 | .017 | | | | | | | | |
| H 075-00 | NOV 11,1963 | 2000 | 39-55S | 109-54W | .051 | .019 | .052 | .021 | | | | | 35 | 8 | | |
| H 076-01 | NOV 12,1963 | 1200 | 40-09S | 109-38W | .058 | .021 | .069 | .026 | 1.9 | 1.4 | 1.3 | 1.3 | | | | |
| H 077-00 | NOV 12,1963 | 2000 | 39-50S | 108-39W | | | | | | | | | 12 | 0 | | |
| H 077-01 | NOV 12,1963 | 2400 | 39-49S | 107-52W | .080 | .020 | .079 | .033 | | | | | | | | |
| H 077-02 | NOV 13,1963 | 0445 | 39-12S | 106-48W | .090 | .042 | .114 | .063 | 1.4 | 4.1 | 4.1 | 4.1 | | | | |
| H 078-01 | NOV 13,1963 | 1145 | 39-12S | 106-48W | .080 | .032 | .062 | .033 | 1.0 | 2.6 | 2.9 | 2.8 | | | | |
| H 078-02 | NOV 13,1963 | 1845 | 39-21S | 105-59W | .063 | .030 | .050 | .026 | | | | | | | | |
| H 079-00 | NOV 13,1963 | 2000 | 39-18S | 105-44W | | | | | | | | | 4 | 0 | | |
| H 079-01 | NOV 13,1963 | 2400 | 39-09S | 104-56W | .062 | .018 | .052 | .023 | | | | | | | | |
| H 080-01 | NOV 14,1963 | 0445 | 38-58S | 103-48W | .060 | .016 | .046 | .018 | 1.7 | 3.8 | 2.8 | 3.3 | | | | |
| H 080-02 | NOV 14,1963 | 0830 | 38-51S | 102-58W | .077 | .015 | .052 | .025 | | | | | | | | |
| H 081-00 | NOV 14,1963 | 1145 | 38-42S | 102-06W | .062 | .016 | .037 | .023 | 1.1 | 2.8 | 2.9 | 2.9 | | | | |
| H 081-01 | NOV 14,1963 | 1500 | 38-36S | 101-34W | .060 | .021 | .025 | .021 | | | | | | | | |
| H 081-02 | NOV 14,1963 | 1845 | 38-36S | 101-34W | .044 | .012 | .018 | .016 | | | | | | | | |
| H 082-00 | NOV 14,1963 | 2000 | 38-32S | 101-21W | | | | | | | | | 6 | 12 | | |
| H 083-01 | NOV 15,1963 | 1145 | 38-25S | 101-06W | .045 | .018 | .055 | .020 | .8 | 5.4 | 5.4 | 5.4 | | | | |
| H 083-02 | NOV 15,1963 | 1845 | 37-50S | 101-08W | .037 | .007 | .036 | .017 | | | | | | | | |
| H 084-00 | NOV 15,1963 | 2000 | 37-37S | 101-07W | | | | | | | | | 48 | 2 | | |
| H 084-01 | NOV 15,1963 | 2400 | 36-55S | 101-07W | .064 | .020 | .049 | .027 | | | | | | | | |
| H 085-01 | NOV 16,1963 | 0530 | 35-58S | 101-06W | .054 | .023 | .062 | .023 | .9 | 4.3 | 3.9 | 4.1 | | | | |
| H 085-02 | NOV 16,1963 | 0830 | 35-22S | 101-02W | .043 | .006 | .025 | .015 | | | | | | | | |
| H 086-00 | NOV 16,1963 | 1145 | 34-44S | 101-01W | .035 | .009 | .028 | .012 | .7 | 3.5 | 3.5 | 3.5 | | | | |
| H 086-01 | NOV 16,1963 | 1830 | 34-44S | 101-01W | .036 | .013 | .040 | .015 | | | | | | | | |
| H 087-00 | NOV 16,1963 | 2000 | 34-43S | 101-02W | | | | | | | | | 37 | 15 | | |
| H 088-01 | NOV 17,1963 | 1145 | 34-49S | 101-18W | .030 | .019 | .039 | .023 | .4 | 2.5 | 2.8 | 2.7 | | | | |
| H 088-02 | NOV 17,1963 | 1830 | 34-42S | 100-30W | .031 | .007 | .032 | .014 | | | | | | | | |
| H 089-00 | NOV 17,1963 | 2000 | 34-40S | 099-54W | | | | | | | | | 44 | 12 | | |
| H 089-01 | NOV 17,1963 | 2400 | 34-32S | 099-11W | .032 | .016 | .032 | .014 | | | | | | | | |
| H 090-01 | NOV 18,1963 | 0830 | 34-11S | 098-13W | .051 | .016 | .044 | .021 | | | | | | | | |
| H 091-00 | NOV 18,1963 | 1145 | 34-05S | 096-27W | .035 | .007 | .046 | .014 | .6 | 3.9 | 3.5 | 3.7 | | | | |
| H 091-01 | NOV 18,1963 | 1500 | 33-60S | 095-57W | .038 | .010 | .033 | .017 | | | | | | | | |
| H 091-02 | NOV 18,1963 | 1815 | 33-52S | 095-19W | .026 | .005 | .037 | .016 | | | | | | | | |

| BIOLOGICAL OBSERVATIONS | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | CHLOROPHYLL | | | CAROT | CARBON FIXATION | | | | ZOOPLANKTON | | | |
| STATION | DATE | TIME | LAT. | LONG. | *a* | *b* | *c* | CP | Dk | Lt | Lt | $\overline{\mathrm{Lt}}$ | S-S | S-L | 20-S | 20-L |
| | | | | | (mg/m³) | | | (mSPU) | (mg/m³-day) | | | | | | | |
| H 092-00 | NOV 18,1963 | 2000 | 33-48S | 094-51W | .031 | .010 | .029 | .014 | | | | | 163 | 2 | | |
| H 093-01 | NOV 19,1963 | 1145 | 33-52S | 094-02W | .038 | d) | e) | f) | .6 | 3.2 | 4.0 | 3.6 | | | | |
| H 093-02 | NOV 19,1963 | 1830 | 33-33S | 093-14W | .035 | .003 | .024 | .015 | | | | | | | | |
| H 094-00 | NOV 19,1963 | 2000 | 33-28S | 092-48W | .022 | .008 | .029 | .011 | | | | | 85 | 3 | | |
| H 094-01 | NOV 19,1963 | 2400 | 33-18S | 092-08W | .029 | .012 | .021 | .010 | | | | | | | | |
| H 094-02 | NOV 20,1963 | 0500 | 33-06S | 091-03W | .031 | .028 | .074 | .014 | 1.2 | 3.2 | 3.4 | 3.3 | | | | |
| H 095-00 | NOV 20,1963 | 0830 | 32-59S | 090-19W | .040 | .016 | .026 | .018 | | | | | | | | |
| H 095-01 | NOV 20,1963 | 1145 | 32-46S | 089-38W | .044 | .011 | .037 | .015 | 1.7 | 5.6 | 5.8 | 5.7 | | | | |
| H 095-02 | NOV 20,1963 | 1500 | 32-40S | 089-00W | .046 | .007 | .030 | .020 | | | | | | | | |
| H 095-03 | NOV 20,1963 | 1830 | 32-28S | 088-12W | .034 | .015 | .031 | .018 | | | | | | | | |
| H 096-00 | NOV 20,1963 | 2015 | 32-23S | 087-51W | .066 | .016 | .051 | .027 | | | | | | | | |
| H 097-01 | NOV 21,1963 | 1145 | 32-13S | 086-45W | .055 | .014 | .051 | .022 | 1.3 | 4.1 | 4.0 | 4.0 | | | | |
| H 097-02 | NOV 21,1963 | 1830 | 32-15S | 085-49W | .051 | .019 | .050 | .024 | | | | | | | | |
| H 098-00 | NOV 21,1963 | 2000 | 32-16S | 085-44W | .079 | .022 | .071 | .032 | | | | | 70 | 5 | | |
| H 098-01 | NOV 21,1963 | 2400 | 32-22S | 085-08W | .057 | .017 | .048 | .026 | | | | | | | | |
| H 098-02 | NOV 22,1963 | 0500 | 32-35S | 084-00W | | | | | 1.0 | 9.4 | 8.5 | 8.9 | | | | |
| H 099-00 | NOV 22,1963 | 0830 | 32-43S | 083-19W | .098 | .032 | .083 | .041 | | | | | | | | |
| H 099-01 | NOV 22,1963 | 1145 | 32-48S | 082-49W | .112 | .029 | .093 | .042 | .9 | 4.2 | 3.1 | 3.7 | | | | |
| H 099-02 | NOV 22,1963 | 1500 | 32-57S | 082-36W | .055 | .012 | .045 | .022 | | | | | | | | |
| H 099-03 | NOV 22,1963 | 1830 | 33-05S | 081-21W | .106 | .032 | .077 | .060 | | | | | | | | |
| H 100-00 | NOV 22,1963 | 2000 | 33-08S | 081-03W | | | | | | | | | 3 | 0 | | |
| H 101-00 | NOV 23,1963 | 0830 | 33-14S | 078-28W | .176 | .048 | .091 | .069 | | | | | | | | |
| H 101-01 | NOV 23,1963 | 1145 | 33-17S | 077-58W | .158 | .039 | .120 | .068 | 2.7 | 7.3 | 7.5 | 7.4 | | | | |
| H 101-02 | NOV 23,1963 | 1500 | 33-17S | 077-06W | .104 | .034 | .069 | .041 | | | | | | | | |
| H 102-00 | NOV 23,1963 | 2000 | 33-18S | 075-55W | .143 | .035 | .091 | .060 | | | | | 82 | 2 | | |
| H 102-01 | NOV 24,1963 | 0500 | 33-17S | 074-42W | .158 | .044 | .099 | .060 | 2.4 | 15.9 | 14.2 | 15.1 | | | | |
| H 102-02 | NOV 24,1963 | 0830 | 33-14S | 073-25W | .761 | .187 | .378 | .215 | | | | | | | | |
| H 102-03 | NOV 24,1963 | 1145 | 33-14S | 073-04W | .250 | .056 | .142 | .079 | 4.1 | 4.1 | 4.0 | 4.1 | | | | |
| H 102-04 | NOV 24,1963 | 1500 | 33-09S | 072-17W | .156 | .045 | .107 | .056 | | | | | | | | |
| H 102-05 | NOV 24,1963 | 1830 | 32-55S | 071-48W | .473 | .128 | .308 | .132 | | | | | | | | |
| H 102-06 | DEC 02,1963 | 1500 | 32-58S | 071-40W | .678 | .207 | .383 | .219 | | | | | | | | |
| H 102-07 | DEC 02,1963 | 1600 | 33-01S | 071-44W | 5.079 | 5.955 | 13.486 | 1.024 | | | | | | | | |
| H 102-08 | DEC 02,1963 | 1700 | 33-04S | 071-50W | 3.897 | .898 | 2.832 | .713 | | | | | | | | |
| H 102-09 | DEC 02,1963 | 1815 | 33-07S | 071-59W | .197 | .059 | .134 | .073 | | | | | | | | |
| H 102-10 | DEC 02,1963 | 1900 | 33-10S | 072-10W | .205 | .066 | .132 | .082 | | | | | | | | |
| H 102-11 | DEC 02,1963 | 2010 | 33-12S | 072-18W | .145 | .046 | .102 | .060 | | | | | | | | |
| H 102-12 | DEC 02,1963 | 2000 | 33-13S | 072-25W | .144 | .028 | .092 | .059 | | | | | | | | |
| H 102-13 | DEC 02,1963 | 2100 | 33-15S | 072-35W | .395 | .126 | .242 | .129 | | | | | | | | |
| H 102-14 | DEC 02,1963 | 2400 | 33-17S | 072-48W | .478 | .172 | .298 | .156 | | | | | | | | |
| H 102-15 | DEC 03,1963 | 0445 | 33-33S | 073-03W | .568 | .140 | .299 | .159 | | | | | | | | |
| H 102-16 | DEC 03,1963 | 0830 | 33-43S | 073-13W | .234 | .060 | .116 | .083 | | | | | | | | |
| H 102-17 | DEC 03,1963 | 1130 | 33-54S | 073-27W | .527 | .157 | .301 | .154 | 1.7 | 3.1 | 2.6 | 2.8 | | | | |
| H 102-18 | DEC 03,1963 | 1845 | 34-10S | 073-54W | .267 | .073 | .147 | .103 | | | | | | | | |
| H 102-19 | DEC 03,1963 | 2400 | 34-24S | 074-13W | .232 | .051 | .126 | .088 | | | | | | | | |
| H 102-20 | DEC 04,1963 | 0445 | 34-42S | 074-31W | .236 | .067 | .134 | .090 | 1.2 | 9.7 | 9.1 | 9.4 | | | | |
| H 102-21 | DEC 04,1963 | 0830 | 34-55S | 074-44W | .313 | .089 | .177 | .114 | | | | | | | | |
| H 102-22 | DEC 04,1963 | 1145 | 35-17S | 074-58W | .213 | .072 | .134 | .075 | 2.5 | 6.5 | 5.4 | 6.0 | | | | |
| H 102-23 | DEC 04,1963 | 1500 | 35-34S | 075-11W | .292 | .107 | .177 | .106 | | | | | | | | |
| H 102-24 | DEC 04,1963 | 1845 | 35-53S | 075-37W | .193 | .049 | .117 | .077 | | | | | | | | |
| H 102-25 | DEC 04,1963 | 2400 | 36-25S | 076-17W | .224 | .055 | .132 | .086 | | | | | | | | |
| H 102-26 | DEC 05,1963 | 0430 | 36-46S | 077-12W | .499 | .074 | .300 | .203 | 1.9 | 23.1 | 22.6 | 22.9 | | | | |
| H 103-00 | DEC 05,1963 | 0830 | 37-06S | 077-55W | .469 | .063 | .241 | .189 | | | | | | | | |
| H 103-01 | DEC 05,1963 | 1145 | 37-04S | 078-26W | .457 | .069 | .283 | .199 | 2.1 | 35.0 | 31.3 | 33.1 | | | | |
| H 103-02 | DEC 05,1963 | 1500 | 37-16S | 079-03W | .132 | .037 | .106 | .051 | | | | | | | | |

BIOLOGICAL OBSERVATIONS

| | | | | | CHLOROPHYLL | | | CAROT | CARBON FIXATION | | | | ZOOPLANKTON | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| STATION | DATE | TIME | LAT. | LONG. | *a* | *b* | *c* | CP | Dk | Lt | Lt | $\overline{\text{Lt}}$ | S-S | S-L | 20-S | 20-L |
| | | | | | (mg/$m^3$) | | | (mSPU) | (mg/$m^3$-day) | | | | | | | |
| H 103-03 | DEC 05,1963 | 1900 | 37-22S | 079-58W | .110 | .031 | .114 | .045 | | | | | | | | |
| H 104-00 | DEC 05,1963 | 2000 | 37-23S | 080-10W | | | | | | | | | 127 | 0 | | |
| H 104-01 | DEC 05,1963 | 2400 | 37-30S | 080-44W | .112 | .039 | .118 | .048 | | | | | | | | |
| H 104-02 | DEC 06,1963 | 0430 | 37-39S | 081-28W | .140 | .040 | .136 | .054 | 3.5 | 9.2 | 10.7 | 10.0 | | | | |
| H 105-00 | DEC 06,1963 | 0830 | 37-49S | 082-15W | .060 | .025 | .026 | .020 | | | | | | | | |
| H 105-01 | DEC 06,1963 | 1145 | 37-47S | 082-39W | .075 | .016 | .044 | .031 | 2.8 | 3.5 | 3.8 | 3.6 | | | | |
| H 105-02 | DEC 06,1963 | 1500 | 37-56S | 083-13W | .067 | .022 | .054 | .028 | | | | | | | | |
| H 105-03 | DEC 06,1963 | 1900 | 38-04S | 084-01W | .068 | .018 | .056 | .028 | | | | | | | | |
| H 106-00 | DEC 06,1963 | 2000 | 38-06S | 084-13W | | | | | | | | | 67 | 45 | | |
| H 106-01 | DEC 06,1963 | 2400 | 38-18S | 084-48W | .055 | .009 | .039 | .025 | | | | | | | | |
| H 106-02 | DEC 07,1963 | 0430 | 38-32S | 085-38W | .071 | .020 | .052 | .028 | 3.0 | 4.0 | 4.7 | 4.4 | | | | |
| H 107-00 | DEC 07,1963 | 0830 | 38-46S | 086-24W | .064 | .017 | .033 | .023 | | | | | | | | |
| H 107-01 | DEC 07,1963 | 1145 | 39-04S | 086-50W | .055 | .014 | .051 | .025 | 2.8 | .7 | .5 | .6 | | | | |
| H 107-02 | DEC 07,1963 | 1500 | 39-18S | 087-23W | .066 | .016 | .051 | .024 | | | | | | | | |
| H 107-03 | DEC 07,1963 | 1900 | 39-33S | 088-10W | .053 | .018 | .050 | .025 | | | | | | | | |
| H 108-00 | DEC 07,1963 | 2000 | 39-36S | 088-22W | | | | | | | | | 142 | 75 | | |
| H 108-01 | DEC 07,1963 | 2400 | 39-51S | 089-00W | .066 | .016 | .051 | .028 | | | | | | | | |
| H 109-01 | DEC 08,1963 | 1145 | 39-23S | 089-43W | .075 | .021 | .057 | .034 | 2.6 | 3.0 | 1.9 | 2.5 | | | | |
| H 109-02 | DEC 08,1963 | 1900 | 39-35S | 090-16W | .064 | .020 | .058 | .027 | | | | | | | | |
| H 110-00 | DEC 08,1963 | 2050 | 39-28S | 090-36W | | | | | | | | | 7 | 189 | | |
| H 110-01 | DEC 08,1963 | 2400 | 39-01S | 090-55W | .077 | .023 | .063 | .031 | | | | | | | | |
| H 110-02 | DEC 09,1963 | 0430 | 38-25S | 091-34W | .104 | .026 | .083 | .042 | 2.0 | 9.3 | 9.6 | 9.4 | | | | |
| H 111-00 | DEC 09,1963 | 0830 | 37-53S | 092-08W | .086 | .023 | .073 | .034 | | | | | | | | |
| H 111-01 | DEC 09,1963 | 1145 | 37-36S | 092-27W | .086 | .027 | .087 | .037 | 1.6 | 7.1 | 6.8 | 6.9 | | | | |
| H 111-02 | DEC 09,1963 | 1900 | 36-56S | 092-55W | .090 | .028 | .084 | .041 | | | | | | | | |
| H 111-03 | DEC 10,1963 | 0445 | 36-10S | 093-30W | .075 | .014 | .062 | .030 | 1.9 | 6.7 | 6.6 | 6.6 | | | | |
| H 112-01 | DEC 10,1963 | 1145 | 35-41S | 093-56W | | | | | 1.2 | 2.8 | 3.4 | 3.1 | | | | |
| H 112-02 | DEC 10,1963 | 1845 | 35-23S | 094-31W | .050 | .008 | .044 | .021 | | | | | | | | |
| H 113-00 | DEC 10,1963 | 2010 | 35-19S | 094-35W | | | | | | | | | 30 | 1 | | |
| H 113-01 | DEC 10,1963 | 2400 | 35-07S | 094-44W | .042 | .014 | .044 | .016 | | | | | | | | |
| H 114-01 | DEC 11,1963 | 1145 | 34-24S | 094-45W | .047 | .034 | .117 | .059 | 1.6 | 1.2 | 1.0 | 1.1 | | | | |
| H 114-02 | DEC 11,1963 | 1845 | 33-24S | 094-52W | .024 | .008 | .019 | .022 | | | | | | | | |
| H 115-00 | DEC 11,1963 | 2000 | 33-14S | 094-53W | | | | | | | | | 36 | 0 | | |
| H 115-01 | DEC 11,1963 | 2200 | 33-14S | 094-53W | .028 | .007 | .009 | .017 | | | | | | | | |
| H 115-02 | DEC 12,1963 | 0445 | 32-12S | 094-53W | .028 | .006 | .018 | .015 | 2.3 | 2.2 | 6.2 | 4.2 | | | | |
| H 116-01 | DEC 12,1963 | 0830 | 31-40S | 094-52W | .020 | .002 | .015 | .009 | | | | | | | | |
| H 116-02 | DEC 12,1963 | 1145 | 30-50S | 094-48W | .016 | .011 | .023 | .011 | 1.6 | 1.3 | 1.1 | 1.2 | | | | |
| H 117-00 | DEC 12,1963 | 1500 | 30-29S | 094-48W | .026 | .007 | .019 | .013 | | | | | | | | |
| H 117-01 | DEC 12,1963 | 1845 | 30-02S | 094-50W | .022 | .003 | .033 | .013 | | | | | | | | |
| H 118-00 | DEC 12,1963 | 2000 | 29-56S | 094-58W | | | | | | | | | 35 | 1 | | |
| H 119-00 | DEC 13,1963 | 0630 | 29-55S | 094-30W | | | | | | | | | 35 | 0 | | |
| H 119-01 | DEC 13,1963 | 1145 | 29-56S | 094-40W | .020 | .008 | .030 | .011 | 2.0 | .4 | .3 | .4 | | | | |
| H 119-02 | DEC 13,1963 | 1845 | 29-10S | 094-56W | .015 | .004 | .017 | .007 | | | | | | | | |
| H 120-00 | DEC 13,1963 | 2200 | 28-37S | 094-56W | .014 | .009 | .017 | .008 | | | | | 17 | 0 | | |
| H 121-01 | DEC 14,1963 | 1145 | 26-14S | 096-53W | .016 | .004 | .019 | .010 | 2.0 | .4 | .4 | .4 | | | | |
| H 122-01 | DEC 14,1963 | 1600 | 25-38S | 096-49W | .016 | .007 | .025 | .009 | | | | | | | | |
| H 123-00 | DEC 14,1963 | 1845 | 25-16S | 094-49W | .013 | .005 | .018 | .006 | | | | | 50 | 0 | | |
| H 124-00 | DEC 15,1963 | 0630 | 24-36S | 095-13W | | | | | | | | | 4 | 0 | | |
| H 124-01 | DEC 15,1963 | 1145 | 24-45S | 095-01W | .020 | .006 | .024 | .012 | 1.9 | 1.1 | .5 | .8 | | | | |
| H 124-02 | DEC 15,1963 | 1830 | 24-00S | 095-02W | .021 | .012 | .026 | .012 | | | | | | | | |
| H 125-00 | DEC 15,1963 | 2200 | 23-30S | 095-02W | | | | | | | | | 21 | 0 | | |
| H 126-01 | DEC 16,1963 | 0830 | 21-53S | 095-04W | .023 | .011 | .017 | .012 | | | | | | | | |
| H 127-00 | DEC 16,1963 | 1145 | 21-16S | 095-02W | .020 | .010 | .012 | .010 | 2.0 | .2 | 1.5 | .9 | | | | |
| H 127-01 | DEC 16,1963 | 1500 | 20-52S | 095-00W | .023 | .011 | .017 | .015 | | | | | | | | |

| | | | | | BIOLOGICAL OBSERVATIONS | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | CHLOROPHYLL | | | CAROT | CARBON FIXATION | | | | ZOOPLANKTON | | | |
| STATION | DATE | TIME | LAT. | LONG. | *a* | *b* | *c* | CP | Dk | Lt | Lt | $\overline{\text{Lt}}$ | S-S | S-L | 20-S | 20-L |
| | | | | | (mg/m$^3$) | | | (mSPU) | (mg/m$^3$-day) | | | | | | | |
| H 128-00 | DEC 16,1963 | 1830 | 20-19S | 095-00W | .053 | .017 | .041 | .022 | | | | | 35 | 0 | | |
| H 128-01 | DEC 16,1963 | 1927 | 20-19S | 094-60W | | | | | | | | | | | | |
| H 129-00 | DEC 17,1963 | 0600 | 19-43S | 095-17W | | | | | | | | | 10 | 0 | | |
| H 129-01 | DEC 17,1963 | 1145 | 19-51S | 095-09W | .096 | .047 | .104 | .058 | 2.7 | 5.4 | 5.8 | 5.6 | | | | |
| H 129-02 | DEC 17,1963 | 1830 | 19-23S | 095-00W | .082 | .024 | .067 | .039 | | | | | | | | |
| H 129-03 | DEC 17,1963 | 2000 | 18-46S | 095-00W | .072 | .027 | .049 | .031 | | | | | | | | |
| H 130-00 | DEC 17,1963 | 2200 | 18-46S | 095-00W | | | | | | | | | 24 | 10 | | |
| H 130-01 | DEC 18,1963 | 0500 | 17-42S | 095-00W | .117 | .061 | .088 | .050 | 2.5 | 10.0 | 10.9 | 10.4 | | | | |
| H 131-01 | DEC 18,1963 | 0900 | 17-05S | 095-01W | .116 | .056 | .085 | .047 | | | | | | | | |
| H 132-00 | DEC 18,1963 | 1145 | 16-30S | 095-03W | .094 | .047 | .074 | .039 | 3.9 | 4.6 | 4.3 | 4.5 | | | | |
| H 132-01 | DEC 18,1963 | 1545 | 15-58S | 095-03W | .085 | .039 | .061 | .047 | | | | | | | | |
| H 133-00 | DEC 18,1963 | 1815 | 15-38S | 095-00W | .085 | .036 | .063 | .046 | | | | | 33 | 10 | | |
| H 133-01 | DEC 18,1963 | 2000 | 15-31S | 095-03W | | | | | | | | | | | | |
| H 134-00 | DEC 19,1963 | 0550 | 14-31S | 095-14W | | | | | | | | | 8 | 0 | | |
| H 134-01 | DEC 19,1963 | 1145 | 14-47S | 095-06W | .154 | .074 | .093 | .070 | 3.6 | 6.6 | 7.4 | 7.0 | | | | |
| H 134-02 | DEC 19,1963 | 1815 | 14-28S | 096-59W | .134 | .055 | .081 | .058 | | | | | | | | |
| H 135-00 | DEC 19,1963 | 2000 | 13-45S | 094-59W | | | | | | | | | 67 | 15 | | |
| H 135-01 | DEC 19,1963 | 2200 | 13-45S | 094-59W | .160 | .082 | .116 | .073 | | | | | | | | |
| H 135-02 | DEC 20,1963 | 0530 | 12-30S | 095-00W | .167 | .085 | .111 | .069 | 1.8 | 12.1 | 12.2 | 12.2 | | | | |
| H 136-01 | DEC 20,1963 | 0830 | 12-04S | 095-00W | .207 | .089 | .137 | .083 | | | | | | | | |
| H 137-00 | DEC 20,1963 | 1145 | 11-27S | 095-03W | .187 | .079 | .100 | .086 | 2.7 | 11.0 | 6.4 | 8.7 | | | | |
| H 137-01 | DEC 20,1963 | 1500 | 10-42S | 095-00W | .141 | .062 | .069 | .062 | | | | | | | | |
| H 138-00 | DEC 20,1963 | 1815 | 10-27S | 095-00W | .157 | .082 | .102 | .068 | | | | | 20 | 25 | | |
| H 138-01 | DEC 20,1963 | 2000 | 10-27S | 095-00W | | | | | | | | | | | | |
| H 139-00 | DEC 21,1963 | 0555 | 09-30S | 094-58W | | | | | | | | | 33 | 0 | | |
| H 139-01 | DEC 21,1963 | 1145 | 09-37S | 094-57W | .186 | .090 | .126 | .108 | 6.7 | 4.9 | 5.8 | 5.4 | | | | |
| H 139-02 | DEC 21,1963 | 1800 | 09-31S | 094-38W | .160 | .065 | .106 | .073 | | | | | | | | |
| H 140-00 | DEC 21,1963 | 2200 | 09-00S | 094-09W | .109 | .047 | .071 | .054 | | | | | 65 | 5 | | |
| H 140-01 | DEC 22,1963 | 0530 | 08-05S | 093-16W | .109 | .052 | .059 | .047 | 2.8 | 9.6 | 11.7 | 10.7 | | | | |
| H 141-01 | DEC 22,1963 | 0830 | 07-46S | 092-59W | .138 | .077 | .093 | .057 | | | | | | | | |
| H 141-02 | DEC 22,1963 | 1145 | 07-21S | 092-30W | .112 | .056 | .071 | .044 | 2.3 | 10.1 | 10.9 | 10.5 | | | | |
| H 142-00 | DEC 22,1963 | 1430 | 07-05S | 092-13W | .093 | .030 | .054 | .041 | | | | | | | | |
| H 142-01 | DEC 22,1963 | 1800 | 06-45S | 092-00W | .109 | .047 | .080 | .051 | | | | | | | | |
| H 143-00 | DEC 22,1963 | 2200 | 06-13S | 091-15W | .170 | .070 | .097 | .079 | | | | | 68 | 2 | | |
| H 144-00 | DFC 23,1963 | 0600 | 05-12S | 090-36W | | | | | | | | | 25 | 0 | 137 | 0 |
| H 144-01 | DEC 23,1963 | 1145 | 05-13S | 090 40W | .130 | .068 | .086 | .057 | 5.6 | 6.7 | 5.8 | 6.3 | | | | |
| H 144-02 | DEC 23,1963 | 1800 | 05-00S | 090-36W | .210 | .107 | .141 | .088 | | | | | | | | |
| H 145-00 | DEC 23,1963 | 2200 | 04-31S | 089-52W | .184 | .088 | .123 | .085 | | | | | 63 | 0 | | |
| H 146-01 | DEC 24,1963 | 0830 | 03-14S | 088-40W | .270 | .125 | .124 | .128 | | | | | | | | |
| H 146-02 | DEC 24,1963 | 1145 | 02-44S | 088-20W | .257 | .116 | .121 | .119 | 5.0 | 28.8 | 30.9 | 29.9 | | | | |
| H 147-00 | DEC 24,1963 | 1400 | 02-28S | 088-04W | .233 | .100 | .110 | .117 | | | | | 32 | 0 | 287 | 25 |
| H 147-01 | DEC 24,1963 | 1510 | 02-28S | 088-04W | | | | | | | | | | | | |
| H 148-00 | DEC 24,1963 | 2200 | 01-35S | 087-18W | .296 | .128 | .185 | .138 | | | | | 207 | 2 | | |
| H 149-00 | DEC 25,1963 | 0545 | 00-33S | 086-24W | .277 | .076 | .180 | .119 | 2.6 | 53.1 | 40.6 | 46.8 | | | | |
| H 149-01 | DEC 25,1963 | 1145 | 00-08N | 085-45W | .298 | .098 | .178 | .121 | 3.5 | 44.2 | 30.9 | 37.6 | | | | |
| H 150-00 | DEC 25,1963 | 1400 | 00-26N | 085-30W | | | | | | | | | 28 | 0 | 72 | 0 |
| H 150-01 | DEC 25,1963 | 1800 | 00-51N | 085-40W | .222 | .060 | .140 | .105 | | | | | | | | |
| H 151-00 | DEC 25,1963 | 2200 | 01-23N | 084-42W | .324 | .094 | .274 | .157 | | | | | 66 | 18 | | |
| H 152-00 | DEC 26,1963 | 0600 | 02-23N | 083-52W | .133 | .027 | .067 | .060 | 2.9 | 12.3 | 11.5 | 11.9 | | | | |
| H 152-01 | DEC 26,1963 | 1145 | 03-21N | 083-04W | .087 | .032 | .055 | .034 | | | | | | | | |
| H 153-00 | DEC 26,1963 | 1400 | 03-42N | 082-45W | | | | | | | | | 9 | 34 | 87 | 0 |
| H 153-01 | DEC 26,1963 | 1800 | 04-04N | 082-23W | .126 | .024 | .044 | .057 | | | | | | | | |
| H 153-02 | DEC 27,1963 | 0615 | 05-16N | 081-25W | .115 | .024 | .063 | .064 | 3.3 | 9.0 | 12.9 | 10.9 | | | | |
| H 153-03 | DEC 27,1963 | 1145 | 06-08N | 080-59W | .085 | .02[illegible] | .041 | .049 | 2.4 | 4.5 | | 9.5 | | | | |

BIOLOGICAL . OBSERVATIONS

| STATION | DATE | TIME | LAT. | LONG. | CHLOROPHYLL | | | CAROT | CARBON FIXATION | | | | ZOOPLANKTON | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | *a* | *b* | *c* | CP | Dk | Lt | Lt | $\overline{Lt}$ | S-S | S-L | 20-S | 20-L |
| | | | | | (mg/$m^3$) | | | (mSPU) | (mg/$m^3$-day) | | | | | | | |
| H 153-04 | DEC 27,1963 | 1800 | 06-53N | 080-16W | 1.303 | .207 | .253 | .285 | | | | | | | | |
| H 153-05 | JAN 03,1964 | 1800 | 08-20N | 079-38W | .329 | .074 | .153 | .122 | | | | | | | | |
| H 153-06 | JAN 04,1964 | 0005 | 07-11N | 080-05W | .766 | .140 | .330 | .210 | | | | | | | | |
| H 153-07 | JAN 04,1964 | 0620 | 06-18N | 081-01W | 1.371 | .225 | .513 | .266 | 3.4 | 47.5 | 47.5 | 47.5 | | | | |
| H 154-00 | JAN 04,1964 | 1145 | 05-37N | 081-50W | 1.712 | .153 | .415 | .345 | 5.5 | 124.7 | 117.8 | 121.3 | 6 | 0 | 86 | 0 |
| H 155-01 | JAN 04,1964 | 1815 | 05-01N | 062-28W | .355 | .048 | .091 | .115 | | | | | | | | |
| H 156-00 | JAN 04,1964 | 2000 | 04-48N | 082-42W | .974 | .071 | .187 | .214 | | | | | 15 | 6 | | |
| H 157-00 | JAN 05,1964 | 0015 | 04-19N | 083-11W | .668 | .087 | .178 | .143 | | | | | | | | |
| H 158-01 | JAN 05,1964 | 0600 | 03-37N | 083-55W | .419 | .063 | .119 | .102 | 3.6 | 26.3 | 24.2 | 25.3 | | | | |
| H 160-00 | JAN 05,1964 | 1145 | 03-16N | 085-04W | .164 | .056 | .082 | .066 | 2.6 | 13.8 | 15.3 | 14.6 | 3 | 0 | 86 | 0 |
| H 161-01 | JAN 05,1964 | 1815 | 02-42N | 085-33W | .110 | .030 | .046 | .048 | | | | | | | | |
| H 162-00 | JAN 05,1964 | 2000 | 02-27N | 085-47W | .107 | .034 | .049 | .061 | | | | | 84 | 6 | | |
| H 163-00 | JAN 06,1964 | 0005 | 01-55N | 086-14W | .103 | .036 | .057 | .052 | | | | | | | | |
| H 164-01 | JAN 06,1964 | 0605 | 01-08N | 086-54W | .154 | .037 | .084 | .062 | 1.3 | 19.7 | 17.8 | 18.8 | | | | |
| H 165-00 | JAN 06,1964 | 0800 | 00-51N | 087-07W | .218 | .055 | .119 | .091 | | | | | | | | |
| H 165-01 | JAN 06,1964 | 1005 | 00-40N | 087-18W | .213 | .056 | .121 | .091 | | | | | | | | |
| H 166-00 | JAN 06,1964 | 1135 | 00-26N | 087-32W | .227 | .061 | .097 | .096 | 2.0 | 21.3 | 23.1 | 22.2 | 9 | 0 | 77 | 0 |
| H 166-01 | JAN 06,1964 | 1500 | 00-11N | 087-49W | .235 | .054 | .098 | .095 | | | | | | | | |
| H 167-01 | JAN 06,1964 | 1818 | 00-13S | 088-17W | .249 | .081 | .129 | .108 | | | | | | | | |
| H 168-00 | JAN 06,1964 | 2000 | 00-26S | 088-29W | .211 | .086 | .109 | .090 | | | | | 192 | 30 | | |
| H 169-00 | JAN 07,1964 | 0005 | 01-03S | 088-50W | .181 | .078 | .116 | .093 | | | | | | | | |
| H 170-01 | JAN 07,1964 | 0550 | 01-52S | 089-23W | .162 | .060 | .091 | .071 | .9 | 20.6 | 20.4 | 20.5 | | | | |
| H 171-00 | JAN 07,1964 | 0800 | 02-07S | 089-42W | .179 | .072 | .101 | .074 | | | | | | | | |
| H 172-00 | JAN 07,1964 | 1145 | 02-39S | 090-13W | .202 | .090 | .102 | .080 | 2.0 | 28.8 | 26.9 | 27.9 | 7 | 17 | 124 | 0 |
| H 173-00 | JAN 07,1964 | 1600 | 02-59S | 090-39W | .204 | .090 | .089 | .091 | | | | | | | | |
| H 173-01 | JAN 07,1964 | 1800 | 03-14S | 090-01W | .152 | .069 | .080 | .065 | | | | | | | | |
| H 174-00 | JAN 07,1964 | 2000 | 03-25S | 091-16W | .142 | .068 | .087 | .063 | | | | | 107 | 15 | | |
| H 175-00 | JAN 08,1964 | 0005 | 03-53S | 091-48W | .153 | .084 | .088 | .062 | | | | | | | | |
| H 176-01 | JAN 08,1964 | 0600 | 04-31S | 089-34W | .196 | .093 | .146 | .083 | 5.0 | 16.3 | 17.2 | 16.8 | | | | |
| H 177-00 | JAN 08,1964 | 0800 | 04-44S | 092-50W | .197 | .083 | .110 | .070 | | | | | | | | |
| H 178-00 | JAN 08,1964 | 1145 | 05-12S | 093-23W | .179 | .081 | .094 | .075 | 3.3 | 17.7 | 16.3 | 17.0 | 12 | 0 | 109 | 0 |
| H 179-00 | JAN 08,1964 | 1600 | 05-34S | 094-00W | .170 | .070 | .077 | .070 | | | | | | | | |
| H 179-01 | JAN 08,1964 | 1815 | 05-45S | 094-12W | .195 | .088 | .119 | .076 | | | | | | | | |
| H 179-02 | JAN 08,1964 | 1830 | 05-45S | 094-12W | .193 | .081 | .116 | .072 | | | | | | | | |
| H 180-00 | JAN 08,1964 | 2000 | 06-01S | 094-32W | .165 | .076 | .118 | .063 | | | | | 82 | 5 | | |
| H 181-00 | JAN 09,1964 | 0005 | 06-24S | 095-05W | .165 | .078 | .095 | .059 | | | | | 216 | 401 | 90 | 545 |
| H 183-00 | JAN 09,1964 | 0800 | 07-22S | 096-09W | .254 | .111 | .165 | .097 | | | | | | | | |
| H 184-00 | JAN 09,1964 | 1145 | 07-45S | 096-53W | .453 | .188 | .343 | .190 | 1.0 | 26.4 | 17.7 | 22.1 | 8 | 0 | 34 | 0 |
| H 185-00 | JAN 09,1964 | 1600 | 08-05S | 097-19W | .251 | .086 | .144 | .117 | | | | | | | | |
| H 185-01 | JAN 09,1964 | 1820 | 08-22S | 097-42W | .176 | .084 | .114 | .074 | | | | | | | | |
| H 186-00 | JAN 09,1964 | 2000 | 08-32S | 097-54W | .143 | .060 | .094 | .063 | | | | | 45 | 14 | | |
| H 187-01 | JAN 10,1964 | 0530 | 09-09S | 098-53W | .141 | .080 | .100 | .060 | .6 | 9.0 | 9.0 | 9.0 | | | | |
| H 188-00 | JAN 10,1964 | 0800 | 09-27S | 098-50W | .153 | .089 | .073 | .058 | | | | | | | | |
| H 189-00 | JAN 10,1964 | 1200 | 09-57S | 099-47W | .086 | .045 | .029 | .028 | 1.2 | 6.1 | 5.3 | 5.7 | 3 | 0 | 40 | 0 |
| H 189-00 | JAN 10,1964 | 1930 | 09-55S | 099-51W | .095 | .047 | .053 | .040 | | | | | 12 | 0 | | |
| H 190-00 | JAN 11,1964 | 0600 | 09-32S | 100-12W | | | | | | | | | 20 | 0 | 50 | 0 |
| H 190-01 | JAN 11,1964 | 1145 | 09-38S | 100-05W | .095 | .047 | .053 | .040 | 1.0 | 8.3 | 8.3 | 8.3 | | | | |
| H 191-01 | JAN 11,1964 | 1810 | 09-09S | 100-05W | .289 | .106 | .251 | .142 | | | | | | | | |
| H 192-00 | JAN 11,1964 | 2000 | 08-53S | 100-07W | .183 | .087 | .139 | .088 | | | | | 22 | 54 | | |
| H 193-00 | JAN 12,1964 | 0005 | 08-13S | 100-13W | .190 | .079 | .151 | .098 | | | | | | | | |
| H 194-01 | JAN 12,1964 | 0555 | 07-10S | 100-22W | .179 | .110 | .123 | .083 | .8 | 24.9 | 24.3 | 24.6 | | | | |
| H 195-00 | JAN 12,1964 | 0800 | 06-48S | 100-25W | .208 | .129 | .118 | .084 | | | | | | | | |
| H 195-01 | JAN 12,1964 | 1145 | 06-09S | 100-25W | .183 | .091 | .093 | .077 | 1.0 | 23.8 | 24.9 | 24.3 | | | | |
| H 196-00 | JAN 12,1964 | 1230 | 06-09S | 100-29W | | | | | | | | | 22 | 0 | 62 | 0 |

| | | | | | BIOLOGICAL OBSERVATIONS | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | CHLOROPHYLL | | | CAROT | CARBON FIXATION | | | | ZOOPLANKTON | | | |
| STATION | DATE | TIME | LAT. | LONG. | *a* | *b* | *c* | CP | Dk | Lt | Lt | L̄t | S-S | S-L | 20-S | 20-L |
| | | | | | | $(mg/m^3)$ | | (mSPU) | | $(mg/m^3$-day) | | | | | | |
| H 197-00 | JAN 12,1964 | 1800 | 05-38S | 100-31W | .186 | .111 | .117 | .071 | | | | | | | | |
| H 197-03 | JAN 12,1964 | 2000 | 05-35S | 100-37W | | | | | | | | | 55 | 38 | | |
| H 198-00 | JAN 13,1964 | 0608 | 05-10S | 100-50W | | | | | | | | | 32 | 0 | 102 | 0 |
| H 198-01 | JAN 13,1964 | 0810 | 05-07S | 100-52W | .223 | .121 | .146 | .107 | | | | | | | | |
| H 198-02 | JAN 13,1964 | 1130 | 05-20S | 100-48W | .171 | .095 | .098 | .076 | 1.4 | 18.5 | 23.1 | 20.8 | | | | |
| H 198-03 | JAN 13,1964 | 1800 | 05-02S | 100-47W | .175 | .101 | .101 | .060 | | | | | | | | |
| H 199-00 | JAN 13,1964 | 2000 | 04-41S | 100-49W | .192 | .094 | .105 | .078 | | | | | 109 | 5 | | |
| H 200-01 | JAN 14,1964 | 0100 | 03-50S | 100-55W | .151 | .076 | .096 | .058 | | | | | | | | |
| H 201-01 | JAN 14,1964 | 0550 | 03-00S | 101-03W | .157 | .065 | .058 | .069 | 1.0 | 22.3 | 24.4 | 23.3 | | | | |
| H 201-02 | JAN 14,1964 | 0630 | 02-55S | 101-03W | .210 | .070 | .112 | .086 | | | | | | | | |
| H 202-00 | JAN 14,1964 | 0800 | 02-37S | 101-06W | .235 | .079 | .119 | .091 | | | | | | | | |
| H 203-00 | JAN 14,1964 | 1200 | 02-02S | 101-18W | .230 | .082 | .109 | .087 | 2.2 | 25.0 | 21.9 | 23.4 | 5 | 0 | 110 | 0 |
| H 204-01 | JAN 14,1964 | 1800 | 01-16S | 101-22W | .178 | .064 | .066 | .077 | | | | | | | | |
| H 204-00 | JAN 14,1964 | 2000 | 01-16S | 101-22W | | | | | | | | | 24 | 10 | | |
| H 205-00 | JAN 15,1964 | 0559 | 00-50S | 101-40W | | | | | | | | | 42 | 0 | 42 | 80 |
| H 205-01 | JAN 15,1964 | 0915 | 00-50S | 101-42W | .244 | .117 | .134 | .105 | | | | | | | | |
| H 205-02 | JAN 15,1964 | 1135 | 01-00S | 101-42W | .240 | .117 | .116 | .107 | 1.4 | 22.9 | 24.5 | 23.7 | | | | |
| H 205-03 | JAN 15,1964 | 1800 | 00-39S | 101-48W | .257 | .127 | .149 | .124 | | | | | | | | |
| H 206-00 | JAN 15,1964 | 2000 | 00-17S | 101-48W | .228 | .117 | .125 | .103 | | | | | 42 | 57 | | |
| H 207-00 | JAN 16,1964 | 0005 | 00-23N | 101-48W | .268 | .103 | .193 | .104 | | | | | | | | |
| H 208-01 | JAN 16,1964 | 0545 | 01-15N | 101-48W | .242 | .104 | .168 | .104 | 1.7 | 30.8 | 33.2 | 32.0 | | | | |
| H 209-00 | JAN 16,1964 | 0800 | 01-48N | 101-48W | .231 | .105 | .165 | .093 | | | | | | | | |
| H 210-00 | JAN 16,1964 | 1200 | 02-26N | 102-11W | .236 | .101 | .132 | .102 | 2.6 | 29.4 | 31.3 | 30.4 | 3 | 0 | 126 | 0 |
| H 211-01 | JAN 16,1964 | 1800 | 03-02N | 101-41W | .265 | .073 | .188 | .118 | | | | | | | | |
| H 212-00 | JAN 17,1964 | 0600 | 03-26N | 101-49W | | | | | | | | | 15 | 0 | 65 | 0 |
| H 212-01 | JAN 17,1964 | 0800 | 03-26N | 101-50W | .103 | .033 | .049 | .046 | | | | | | | | |
| H 212-02 | JAN 17,1964 | 1130 | 03-18N | 101-54W | .114 | .040 | .045 | .057 | 1.3 | 14.6 | 12.1 | 13.3 | | | | |
| H 212-03 | JAN 17,1964 | 1800 | 03-38N | 102-05W | .128 | .042 | .044 | .055 | | | | | | | | |
| H 213-00 | JAN 17,1964 | 2000 | 04-02N | 102-06W | .083 | .022 | .040 | .039 | | | | | | | | |
| H 214-00 | JAN 18,1964 | 0005 | 04-41N | 102-06W | .094 | .025 | .040 | .043 | | | | | | | | |
| H 215-01 | JAN 18,1964 | 0600 | 05-42N | 102-06W | .073 | .023 | .025 | .036 | 1.2 | 12.4 | 12.0 | 12.2 | | | | |
| H 216-00 | JAN 18,1964 | 0800 | 06-03N | 102-06W | .072 | .013 | .013 | .034 | | | | | | | | |
| H 217-00 | JAN 18,1964 | 1200 | 06-37N | 102-06W | .110 | .025 | .061 | .053 | 10.3 | 13.5 | 14.8 | 14.2 | 9 | 0 | 67 | 0 |
| H 218-00 | JAN 18,1964 | 1600 | 07-17N | 102-00W | .124 | .027 | .060 | .048 | | | | | 20 | 3 | | |
| H 218-01 | JAN 18,1964 | 1750 | 07-25N | 102-10W | .133 | .043 | .062 | .058 | | | | | | | | |
| H 218-02 | JAN 18,1964 | 2010 | 07-29N | 102-15W | | | | | | | | | | | | |
| H 219-00 | JAN 19,1964 | 0600 | 07-49N | 102-45W | | | | | | | | | 6 | 0 | | |
| H 219-01 | JAN 19,1964 | 0845 | 07-50N | 102-45W | .126 | .030 | .055 | .048 | | | | | | | | |
| H 219-02 | JAN 19,1964 | 1130 | 07-47N | 102-37W | .137 | .049 | .065 | .055 | 2.1 | 10.5 | 19.3 | 14.9 | | | | |
| H 219-03 | JAN 19,1964 | 1750 | 08-10N | 102-25W | .097 | .042 | .056 | .057 | | | | | | | | |
| H 220-00 | JAN 19,1964 | 2000 | 08-33N | 102-27W | .068 | .032 | .043 | .035 | | | | | 24 | 5 | | |
| H 221-00 | JAN 20,1964 | 0005 | 09-21N | 102-28W | .059 | .025 | .022 | .035 | | | | | | | | |
| H 222-01 | JAN 20,1964 | 0610 | 10-10N | 102-39W | .199 | .066 | .081 | .087 | 1.3 | 32.5 | 31.1 | 31.8 | | | | |
| H 223-00 | JAN 20,1964 | 0800 | 10-32N | 102-48W | .183 | .059 | .098 | .081 | | | | | | | | |
| H 224-00 | JAN 20,1964 | 1200 | 11-02N | 102-54W | .148 | .056 | .073 | .073 | 1.2 | 22.3 | 19.6 | 21.0 | 6 | 0 | 225 | 0 |
| H 225-00 | JAN 20,1964 | 1800 | 12-02N | 103-04W | .105 | .037 | .033 | .066 | | | | | 55 | 5 | | |
| H 225-00 | JAN 20,1964 | 2000 | 12-02N | 103-04W | | | | | | | | | | | | |
| H 226-00 | JAN 21,1964 | 0618 | 12-44N | 103-28W | | | | | | | | | 25 | 0 | 174 | 0 |
| H 226-01 | JAN 21,1964 | 0815 | 11-40N | 103-28W | .156 | .037 | .072 | .073 | | | | | | | | |
| H 226-02 | JAN 21,1964 | 1130 | 11-53N | 103-21W | .138 | .038 | .052 | .069 | 1.8 | 23.1 | 18.9 | 21.0 | | | | |
| H 226-03 | JAN 21,1964 | 1800 | 12-39N | 103-29W | .093 | .032 | .056 | .052 | | | | | | | | |
| H 227-00 | JAN 21,1964 | 2000 | 13-01N | 103-32W | .145 | .039 | .057 | .068 | | | | | 77 | 5 | | |
| H 228-00 | JAN 22,1964 | 0005 | 13-29N | 103-38W | .086 | .013 | .035 | .041 | | | | | | | | |
| H 229-01 | JAN 22,1964 | 0700 | 14-38N | 103-45W | .083 | .021 | .052 | .040 | 1.2 | 13.7 | 13.4 | 13.5 | | | | |

| BIOLOGICAL OBSERVATIONS | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | CHLOROPHYLL | | | CAROT | CARBON FIXATION | | | | ZOOPLANKTON | | | |
| STATION | DATE | TIME | LAT. | LONG. | *a* | *b* | *c* | CP | Dk | Lt | Lt | $\bar{\text{Lt}}$ | S-S | S-L | 20-S | 20-L |
| | | | | | (mg/m$^3$) | | | (mSPU) | (mg/m$^3$-day) | | | | | | | |
| H 230-00 | JAN 22,1964 | 0800 | 13-58N | 103-49W | .096 | .031 | .055 | .047 | | | | | 14 | 0 | 180 | 0 |
| H 231-01 | JAN 22,1964 | 1245 | 15-35N | 103-55W | .064 | .016 | .016 | .029 | 2.7 | 6.7 | 7.4 | 7.0 | | | | |
| H 231-02 | JAN 22,1964 | 1845 | 16-44N | 104-02W | .083 | .015 | .024 | .045 | | | | | | | | |
| H 231-03 | JAN 22,1964 | 2155 | 17-12N | 104-09W | .072 | .013 | .013 | .038 | | | | | | | | |
| H 231-04 | JAN 23,1964 | 0215 | 17-56N | 104-16W | .078 | .024 | .042 | .042 | | | | | | | | |
| H 231-05 | JAN 23,1964 | 0800 | 18-56N | 104-20W | .192 | .039 | .055 | .091 | | | | | | | | |
| H 231-06 | JAN 30,1964 | 1830 | 18-36N | 104-41W | .130 | .041 | .055 | .060 | | | | | | | | |
| H 231-07 | JAN 31,1964 | 0010 | 17-52N | 105-40W | .103 | .028 | .052 | .048 | | | | | | | | |
| H 231-08 | JAN 31,1964 | 0600 | 17-16N | 106-18W | .075 | .029 | .040 | .042 | | | | | | | | |
| H 233-00 | JAN 31,1964 | 1200 | 16-18N | 107-21W | .066 | .027 | .036 | .029 | 1.4 | 17.2 | 18.1 | 17.6 | 5 | 0 | 75 | 0 |
| H 234-00 | JAN 31,1964 | 1600 | 15-52N | 107-49W | .129 | .057 | .053 | .053 | | | | | | | | |
| H 234-01 | JAN 31,1964 | 1805 | 15-37N | 108-05W | .107 | .044 | .037 | .042 | | | | | | | | |
| H 235-00 | JAN 31,1964 | 2000 | 15-24N | 108-20W | .221 | .078 | .109 | .103 | | | | | 87 | 5 | | |
| H 236-00 | FEB 01,1964 | 0005 | 15-01N | 108-46W | .107 | .046 | .056 | .049 | | | | | | | | |
| H 237-00 | FEB 01,1964 | 0610 | 14-32N | 109-44W | | | | | | | | | 10 | 0 | 105 | 12 |
| H 237-01 | FEB 01,1964 | 0730 | 14-30N | 109-45W | .274 | .120 | .142 | .106 | | | | | | | | |
| H 237-02 | FEB 01,1964 | 1200 | 14-31N | 109-36W | .248 | .098 | .116 | .103 | 1.3 | 22.1 | 10.3 | 16.2 | | | | |
| H 237-03 | FEB 01,1964 | 1800 | 14-14N | 109-40W | .202 | .083 | .085 | .104 | | | | | | | | |
| H 238-00 | FEB 01,1964 | 2000 | 14-02N | 109-55W | .208 | .103 | .108 | .096 | | | | | 100 | 0 | | |
| H 239-00 | FEB 02,1964 | 0005 | 13-37N | 110-23W | .235 | .113 | .133 | .103 | | | | | | | | |
| H 240-01 | FEB 02,1964 | 0535 | 12-56N | 111-06W | .163 | .042 | .074 | .071 | 1.3 | 6.9 | 23.5 | 15.2 | | | | |
| H 241-00 | FEB 02,1964 | 0800 | 12-38N | 111-26W | .190 | .056 | .095 | .076 | | | | | | | | |
| H 242-00 | FEB 02,1964 | 1200 | 12-13N | 111-58W | .187 | .063 | .070 | .076 | 1.5 | 18.0 | 21.3 | 19.7 | 5 | 0 | 115 | 0 |
| H 243-00 | FEB 02,1964 | 1600 | 11-45N | 112-24W | .782 | .080 | .117 | .123 | | | | | | | | |
| H 243-01 | FEB 02,1964 | 1730 | 11-38N | 112-36W | .177 | .045 | .061 | .082 | | | | | | | | |
| H 244-00 | FEB 02,1964 | 2000 | 11-16N | 112-56W | .176 | .051 | .089 | .101 | | | | | 880 | 20 | | |
| H 246-00 | FEB 03,1964 | 0610 | 11-21N | 113-16W | | | | | | | | | 32 | 0 | 190 | 0 |
| H 246-01 | FEB 03,1964 | 0930 | 11-22N | 113-35W | .111 | .044 | .054 | .060 | | | | | | | | |
| H 246-02 | FEB 03,1964 | 1130 | 11-15N | 113-26W | .147 | .043 | .041 | .067 | 1.4 | 14.6 | 14.6 | 14.6 | | | | |
| H 246-03 | FEB 03,1964 | 1735 | 10-48N | 113-37W | .144 | .050 | .070 | .064 | | | | | | | | |
| H 247-00 | FEB 03,1964 | 2000 | 10-29N | 113-58W | .068 | .026 | .015 | .038 | | | | | 70 | 0 | | |
| H 248-01 | FEB 04,1964 | 0100 | 09-58N | 114-29W | .061 | .024 | .021 | .038 | | | | | | | | |
| H 249-01 | FEB 04,1964 | 0535 | 09-25N | 115-02W | .055 | .015 | .023 | .031 | 1.0 | 8.8 | 6.5 | 7.7 | | | | |
| H 250-00 | FEB 04,1964 | 0800 | 09-06N | 115-21W | .078 | .020 | .034 | .041 | | | | | | | | |
| H 251-00 | FEB 04,1964 | 1200 | 08-41N | 115-58W | .064 | .019 | .024 | .032 | 1.5 | 11.9 | 10.1 | 11.0 | 6 | 0 | 54 | 0 |
| H 252-00 | FEB 04,1964 | 1600 | 08-08N | 116-17W | .087 | .029 | .032 | .045 | | | | | | | | |
| H 252-01 | FEB 04,1964 | 1750 | 07-48N | 116-33W | .052 | .020 | .021 | .028 | | | | | | | | |
| H 253-00 | FEB 04,1964 | 2000 | 07-29N | 116-37W | .067 | .014 | .026 | .039 | | | | | 35 | 5 | | |
| H 254-00 | FEB 05,1964 | 0610 | 07-41N | 117-10W | | | | | | | | | 4 | 0 | 65 | 0 |
| H 254-01 | FEB 05,1964 | 0915 | 07-41N | 117-10W | .082 | .026 | .037 | .043 | | | | | | | | |
| H 254-02 | FEB 05,1964 | 1130 | 07-38N | 117-00W | .078 | .024 | .042 | .041 | 1.9 | 4.1 | 3.6 | 3.8 | | | | |
| H 254-03 | FEB 05,1964 | 1735 | 07-12N | 117-10W | .119 | .037 | .066 | .057 | | | | | | | | |
| H 255-00 | FEB 05,1964 | 2000 | 06-55N | 117-27W | .103 | .028 | .052 | .051 | | | | | 43 | 7 | | |
| H 256-00 | FEB 06,1964 | 0005 | 06-31N | 117-54W | .133 | .042 | .073 | .059 | | | | | | | | |
| H 257-01 | FEB 06,1964 | 0545 | 05-54N | 118-32W | .171 | .059 | .107 | .071 | 1.5 | 19.3 | 19.3 | 19.3 | | | | |
| H 258-00 | FEB 06,1964 | 0800 | 05-36N | 118-53W | .135 | .038 | .064 | .054 | | | | | | | | |
| H 259-00 | FEB 06,1964 | 1200 | 05-16N | 119-13W | .133 | .034 | .069 | .055 | 1.3 | 27.9 | 25.9 | 26.9 | 5 | 0 | 180 | 0 |
| H 260-00 | FEB 06,1964 | 1600 | 04-52N | 119-38W | .215 | .068 | .122 | .091 | | | | | | | | |
| H 260-01 | FEB 06,1964 | 1730 | 04-41N | 119-48W | .194 | .068 | .126 | .079 | | | | | | | | |
| H 261-00 | FEB 06,1964 | 2000 | 04-17N | 120-00W | .189 | .067 | .108 | .081 | | | | | 157 | 55 | | |
| H 263-00 | FEB 07,1964 | 0605 | 04-28N | 120-28W | | | | | | | | | 13 | 0 | 250 | 37 |
| H 263-01 | FEB 07,1964 | 0900 | 04-28N | 120-28W | .184 | .073 | .107 | .077 | | | | | | | | |
| H 263-02 | FEB 07,1964 | 1130 | 04-19N | 120-29W | .232 | .095 | .141 | .103 | 1.2 | 11.5 | 10.0 | 10.8 | | | | |
| H 263-03 | FEB 07,1964 | 1730 | 03-49N | 120-46W | .244 | .120 | .154 | .113 | | | | | | | | |

| | | | | | BIOLOGICAL OBSERVATIONS | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | CHLOROPHYLL | | | CAROT | CARBON FIXATION | | | | ZOOPLANKTON | | | |
| STATION | DATE | TIME | LAT. | LONG. | *a* | *b* | *c* | CP | Dk | Lt | Lt | $\overline{Lt}$ | S-S | S-L | 20-S | 20-L |
| | | | | | (mg/$m^3$) | | | (mSPU) | (mg/$m^3$-day) | | | | | | | |
| H 264-00 | FEB 07,1964 | 2000 | 03-29N | 121-04W | .201 | .095 | .141 | .095 | | | | | 52 | 13 | | |
| H 265-00 | FEB 08,1964 | 0005 | 03-04N | 121-26W | .175 | .069 | .106 | .079 | | | | | | | | |
| H 266-01 | FEB 08,1964 | 0540 | 02-23N | 122-05W | .196 | .095 | .123 | .086 | 1.0 | 14.9 | 12.1 | 13.5 | | | | |
| H 267-00 | FEB 08,1964 | 0800 | 02-04N | 122-04W | .191 | .105 | .118 | .077 | | | | | | | | |
| H 268-00 | FEB 08,1964 | 1200 | 01-38N | 123-11W | .142 | .074 | .072 | .064 | .9 | 12.7 | 11.0 | 11.8 | 3 | 0 | 115 | 0 |
| H 269-00 | FEB 08,1964 | 1600 | 01-06N | 123-40W | .159 | .057 | .095 | .072 | | | | | | | | |
| H 269-01 | FEB 08,1964 | 1738 | 00-53N | 123-49W | .149 | .070 | .081 | .071 | | | | | | | | |
| H 270-00 | FEB 08,1964 | 2000 | 00-27N | 124-00W | .110 | .060 | .064 | .058 | | | | | 65 | 4 | | |
| H 271-00 | FEB 09,1964 | 0605 | 00-49N | 124-24W | | | | | | | | | 39 | 0 | 145 | 10 |
| H 271-01 | FEB 09,1964 | 0845 | 00-49N | 124-24W | .154 | .069 | .067 | .072 | | | | | | | | |
| H 271-02 | FEB 09,1964 | 1130 | 00-38N | 124-23W | .139 | .054 | .091 | .064 | 1.1 | 9.5 | 7.3 | 8.4 | | | | |
| H 271-03 | FEB 09,1964 | 1800 | 00-19N | 124-33W | .122 | .054 | .082 | .061 | | | | | | | | |
| H 272-00 | FEB 09,1964 | 2000 | 00-04N | 124-46W | .134 | .067 | .000 | .056 | | | | | 64 | 212 | | |
| H 273-00 | FEB 10,1964 | 0005 | 00-23S | 125-09W | .113 | .058 | .020 | .054 | | | | | | | | |
| H 274-01 | FEB 10,1964 | 0530 | 01-00S | 126-06W | .143 | .056 | .097 | .066 | 1.0 | 10.1 | 10.1 | 10.1 | | | | |
| H 275-00 | FEB 10,1964 | 0800 | 01-20S | 126-11W | .109 | .047 | .086 | .051 | | | | | | | | |
| H 276-00 | FEB 10,1964 | 1200 | 01-50S | 126-50W | .149 | .077 | .097 | .068 | .9 | 9.4 | 11.3 | 10.4 | 3 | 0 | 65 | 0 |
| H 277-00 | FEB 10,1964 | 1600 | 02-19S | 127-10W | .104 | .051 | .054 | .049 | | | | | | | | |
| H 277-01 | FEB 10,1964 | 1739 | 02-32S | 127-20W | .128 | .066 | .088 | .057 | | | | | | | | |
| H 278-00 | FEB 10,1964 | 2000 | 02-57S | 127-38W | .107 | .044 | .079 | .048 | | | | | 82 | 18 | | |
| H 280-00 | FEB 11,1964 | 0530 | 03-07S | 128-24W | | | | | | | | | 10 | 0 | 130 | 25 |
| H 280-01 | FEB 11,1964 | 0930 | 03-09S | 128-23W | .113 | .057 | .086 | .049 | | | | | | | | |
| H 280-02 | FEB 11,1964 | 1130 | 03-16S | 128-18W | .100 | .046 | .051 | .047 | 1.4 | 8.6 | 8.4 | 8.5 | | | | |
| H 280-03 | FEB 11,1964 | 1745 | 03-45S | 128-36W | .092 | .052 | .062 | .045 | | | | | | | | |
| H 281-00 | FEB 11,1964 | 2000 | 04-00S | 128-54W | .085 | .050 | .068 | .039 | | | | | | | | |
| H 282-00 | FEB 12,1964 | 0005 | 04-26S | 129-20W | .111 | .073 | .084 | .056 | | | | | | | | |
| H 283-01 | FEB 12,1964 | 0525 | 05-16S | 130-02W | .113 | .058 | .074 | .053 | 1.0 | 9.5 | 8.9 | 9.2 | | | | |
| H 284-00 | FEB 12,1964 | 0800 | 05-35S | 130-20W | .118 | .051 | .087 | .054 | | | | | | | | |
| H 285-00 | FEB 12,1964 | 1200 | 06-08S | 130-49W | .111 | .056 | .067 | .053 | 4.3 | 2.1 | 2.9 | 2.5 | 7 | 0 | 66 | 0 |
| H 286-01 | FEB 12,1964 | 1730 | 06-33S | 131-14W | .103 | .063 | .067 | .047 | | | | | | | | |
| H 286-00 | FEB 12,1964 | 2000 | 06-30S | 131-15W | | | | | | | | | 42 | 60 | | |
| H 287-00 | FEB 13,1964 | 0556 | 06-22S | 131-42W | | | | | | | | | 8 | 0 | 40 | 0 |
| H 287-01 | FEB 13,1964 | 0845 | 06-22S | 131-42W | .112 | .071 | .064 | .048 | | | | | | | | |
| H 287-02 | FEB 13,1964 | 1130 | 06-30S | 131-40W | .134 | .057 | .082 | .056 | 2.8 | 4.3 | 2.9 | 3.6 | | | | |
| H 287-03 | FEB 13,1964 | 1748 | 07-01S | 131-53W | .129 | .063 | .080 | .059 | | | | | | | | |
| H 288-00 | FEB 13,1964 | 2000 | 07-17S | 132-10W | .117 | .064 | .077 | .054 | | | | | 46 | 22 | | |
| H 289-00 | FEB 14,1964 | 0005 | 07-39S | 132-34W | .090 | .054 | .052 | .033 | | | | | | | | |
| H 289-01 | FEB 14,1964 | 0515 | 08-18S | 133-18W | .117 | .063 | .088 | .054 | 1.2 | 6.9 | 4.4 | 5.7 | | | | |
| H 291-00 | FEB 14,1964 | 0800 | 08-38S | 133-40W | .126 | .071 | .086 | .052 | | | | | | | | |
| H 292-00 | FEB 14,1964 | 1200 | 09-10S | 134-10W | .070 | .038 | .058 | .034 | 1.4 | 3.6 | 4.3 | 3.9 | 3 | 0 | 30 | 0 |
| H 293-00 | FEB 14,1964 | 1600 | 09-35S | 134-39W | .077 | .039 | .052 | .033 | | | | | | | | |
| H 293-01 | FEB 14,1964 | 1740 | 09-47S | 134-49W | .093 | .043 | .069 | .040 | | | | | | | | |
| H 294-00 | FEB 14,1964 | 1900 | 10-03S | 134-55W | | | | | | | | | 16 | 27 | | |
| H 294-01 | FEB 14,1964 | 2045 | 10-03S | 134-55W | .086 | .042 | .064 | .043 | | | | | | | | |
| H 295-00 | FEB 15,1964 | 0600 | 09-50S | 135-36W | | | | | | | | | 5 | 0 | 25 | 0 |
| H 295-01 | FEB 15,1964 | 0745 | 09-50S | 135-36W | .106 | .057 | .069 | .045 | | | | | | | | |
| H 295-02 | FEB 15,1964 | 1132 | 09-56S | 135-16W | .095 | .046 | .065 | .039 | .7 | 5.4 | 5.2 | 5.3 | | | | |
| H 295-03 | FEB 15,1964 | 1751 | 09-38S | 135-23W | .117 | .061 | .069 | .015 | | | | | | | | |
| H 296-00 | FEB 15,1964 | 2000 | 09-20S | 135-36W | .134 | .057 | .082 | .014 | | | | | 16 | 10 | | |
| H 298-01 | FEB 16,1964 | 0530 | 08-12S | 136-27W | .115 | .060 | .093 | .049 | .9 | 7.9 | 8.9 | 8.4 | | | | |
| H 299-00 | FEB 16,1964 | 0800 | 07-50S | 136-42W | .122 | .062 | .075 | .053 | | | | | 4 | 0 | 35 | 0 |
| H 300-00 | FEB 16,1964 | 1125 | 07-28S | 136-59W | .113 | .058 | .074 | .048 | 1.0 | 3.7 | 4.5 | 4.1 | | | | |
| H 301-00 | FEB 16,1964 | 1600 | 06-55S | 137-23W | .115 | .063 | .047 | .051 | | | | | | | | |
| H 301-01 | FEB 16,1964 | 1745 | 06-40S | 137-35W | .131 | .058 | .083 | .058 | | | | | | | | |

BIOLOGICAL OBSERVATIONS

| STATION | DATE | TIME | LAT. | LONG. | CHLOROPHYLL | | | CAROT | CARBON FIXATION | | | | ZOOPLANKTON | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | *a* | *b* | *c* | CP | Dk | Lt | Lt | $\overline{\text{Lt}}$ | S-S | S-L | 20-S | 20-L |
| | | | | | (mg/m$^3$) | | | (mSPU) | (mg/m$^3$-day) | | | | | | | |
| H 302-00 | FEB 16,1964 | 2000 | 06-20S | 137-49W | .124 | .060 | .086 | .057 | | | | | 12 | 0 | 105 | 0 |
| H 303-00 | FEB 17,1964 | 0025 | 05-54S | 138-08W | .105 | .062 | .066 | .046 | | | | | | | | |
| H 304-01 | FEB 17,1964 | 0515 | 05-14S | 138-42W | .115 | .066 | .067 | .058 | .6 | 12.4 | 14.4 | 13.4 | | | | |
| H 305-00 | FEB 17,1964 | 0800 | 04-48S | 139-00W | .138 | .067 | .081 | .058 | | | | | 8 | 0 | 80 | 0 |
| H 305-01 | FEB 17,1964 | 1130 | 04-26S | 139-14W | .122 | .054 | .070 | .053 | 1.0 | 6.1 | 8.1 | 7.1 | | | | |
| H 306-00 | FEB 17,1964 | 1600 | 03-47S | 139-48W | .099 | .049 | .059 | .046 | | | | | | | | |
| H 306-01 | FEB 17,1964 | 1750 | 03-40S | 139-49W | .095 | .046 | .065 | .042 | | | | | | | | |
| H 307-00 | FEB 17,1964 | 2000 | 03-10S | 140-12W | .100 | .037 | .058 | .043 | | | | | 38 | 8 | 160 | 0 |
| H 308-01 | FEB 18,1964 | 0030 | 02-40S | 140-33W | .082 | .033 | .053 | .039 | | | | | | | | |
| H 309-00 | FEB 18,1964 | 0400 | 02-11S | 140-54W | .102 | .046 | .081 | .044 | | | | | | | | |
| H 309-01 | FEB 18,1964 | 0535 | 01-53S | 141-08W | .098 | .038 | .059 | .042 | 1.0 | 12.6 | 11.3 | 12.0 | | | | |
| H 310-00 | FEB 18,1964 | 0800 | 01-32S | 141-22W | .116 | .049 | .080 | .048 | | | | | 4 | 0 | 70 | 0 |
| H 311-00 | FEB 18,1964 | 1130 | 01-04S | 141-41W | .111 | .044 | .066 | .046 | .4 | 8.2 | 9.5 | 8.8 | | | | |
| H 312-00 | FEB 18,1964 | 1600 | 00-30S | 142-07W | .111 | .044 | .066 | .051 | | | | | | | | |
| H 312-01 | FEB 18,1964 | 1755 | 00-12S | 142-21W | .123 | .048 | .054 | .055 | | | | | | | | |
| H 313-00 | FEB 18,1964 | 2000 | 00-07N | 142-35W | .131 | .058 | .083 | .063 | | | | | 17 | 38 | 145 | 200 |
| H 314-00 | FEB 19,1964 | 0005 | 00-34N | 142-54W | .115 | .057 | .073 | .056 | | | | | | | | |
| H 315-00 | FEB 19,1964 | 0400 | 01-06N | 143-17W | .113 | .055 | .066 | .060 | | | | | | | | |
| H 315-01 | FEB 19,1964 | 0540 | 01-21N | 143-34W | .134 | .049 | .077 | .069 | 1.1 | 18.2 | 13.3 | 15.7 | | | | |
| H 316-00 | FEB 19,1964 | 0800 | 01-42N | 143-48W | .166 | .071 | .090 | .073 | | | | | 14 | 0 | 180 | 0 |
| H 317-00 | FEB 19,1964 | 1200 | 02-10N | 144-13W | .143 | .066 | .068 | .063 | 1.1 | 7.7 | 7.4 | 7.5 | | | | |
| H 318-00 | FEB 19,1964 | 1600 | 02-44N | 144-35W | .136 | .061 | .066 | .061 | | | | | | | | |
| H 318-01 | FEB 19,1964 | 1800 | 03-05N | 144-46W | .186 | .073 | .106 | .077 | | | | | | | | |
| H 319-00 | FEB 19,1964 | 2000 | 03-23N | 144-58W | .202 | .084 | .128 | .085 | | | | | 23 | 0 | 155 | 15 |
| H 320-00 | FEB 20,1964 | 0005 | 03-49N | 145-17W | .170 | .080 | .101 | .073 | | | | | | | | |
| H 321-00 | FEB 20,1964 | 0400 | 04-22N | 145-40W | .192 | .093 | .117 | .083 | | | | | 116 | 402 | 200 | 552 |
| H 322-00 | FEB 20,1964 | 0800 | 05-02N | 145-59W | .183 | .088 | .127 | .067 | | | | | 12 | 0 | 155 | 0 |
| H 323-00 | FEB 20,1964 | 1200 | 05-33N | 146-12W | .160 | .082 | .074 | .067 | .7 | 12.1 | 15.7 | 13.9 | | | | |
| H 323-00 | FEB 20,1964 | 1210 | 05-33N | 146-12W | .168 | .066 | .081 | .065 | | | | | | | | |
| H 324-00 | FEB 20,1964 | 1600 | 06-07N | 146-33W | .201 | .071 | .108 | .082 | | | | | | | | |
| H 324-01 | FEB 20,1964 | 1800 | 06-28N | 146-40W | .171 | .064 | .092 | .070 | | | | | | | | |
| H 325-00 | FEB 20,1964 | 2000 | 06-43N | 146-49W | .191 | .073 | .123 | .087 | | | | | 25 | 7 | 220 | 0 |
| H 326-00 | FEB 21,1964 | 0005 | 07-08N | 147-07W | .095 | .039 | .060 | .018 | | | | | | | | |
| H 327-00 | FEB 21,1964 | 0400 | 07-40N | 147-28W | .148 | .054 | .095 | .003 | | | | | | | | |
| H 327-01 | FEB 21,1964 | 0605 | 07-56N | 147-36W | .098 | .030 | .054 | .048 | 1.1 | 6.6 | 5.5 | 6.1 | | | | |
| H 328-00 | FEB 21,1964 | 0800 | 08-11N | 147-48W | .112 | .036 | .061 | .049 | | | | | 21 | 0 | 88 | 0 |
| H 329-00 | FEB 21,1964 | 1200 | 08-34N | 148-04W | .100 | .037 | .058 | .047 | .7 | 5.1 | 5.2 | 5.2 | | | | |
| H 330-00 | FEB 21,1964 | 1600 | 09-06N | 148-31W | .116 | .046 | .061 | .054 | | | | | | | | |
| H 330-01 | FEB 21,1964 | 1820 | 09-27N | 148-48W | .160 | .051 | .068 | .070 | | | | | | | | |
| H 331-00 | FEB 21,1964 | 2000 | 09-40N | 148-58W | .135 | .037 | .076 | .057 | | | | | 80 | 5 | 85 | 0 |
| H 332-00 | FEB 22,1964 | 0005 | 10-07N | 149-16W | .114 | .038 | .068 | .050 | | | | | | | | |
| H 333-00 | FEB 22,1964 | 0400 | 10-37N | 149-36W | .112 | .032 | .053 | .055 | | | | | | | | |
| H 333-01 | FEB 22,1964 | 0605 | 10-58N | 149-49W | .113 | .028 | .057 | .045 | .7 | 16.8 | 15.6 | 16.2 | | | | |
| H 334-00 | FEB 22,1964 | 0800 | 11-14N | 149-59W | .117 | .034 | .059 | .049 | | | | | 100 | 0 | 85 | 0 |
| H 335-00 | FEB 22,1964 | 1200 | 11-44N | 150-17W | .071 | .023 | .037 | .036 | .9 | 2.3 | 1.8 | 2.1 | | | | |
| H 336-00 | FEB 22,1964 | 1600 | 12-17N | 150-38W | .105 | .034 | .068 | .050 | | | | | | | | |
| H 336-01 | FEB 22,1964 | 1805 | 12-33N | 150-50W | .116 | .037 | .067 | .053 | | | | | | | | |
| H 337-00 | FEB 22,1964 | 2000 | 12-50N | 151-01W | .083 | .022 | .040 | .033 | | | | | 18 | 0 | 80 | 0 |
| H 338-00 | FEB 23,1964 | 0005 | 13-15N | 151-16W | .073 | .026 | .044 | .030 | | | | | | | | |
| H 339-00 | FEB 23,1964 | 0400 | 13-47N | 151-34W | .061 | .022 | .056 | .025 | | | | | | | | |
| H 339-01 | FEB 23,1964 | 0610 | 14-08N | 151-56W | .066 | .027 | .059 | .028 | | | | | | | | |
| H 340-00 | FEB 23,1964 | 0800 | 14-23N | 152-07W | .061 | .025 | .064 | .025 | | | | | 8 | 0 | 20 | 0 |
| H 341-00 | FEB 23,1964 | 1200 | 14-51N | 152-21W | .039 | .013 | .037 | .015 | 4.8 | 2.2 | | 2.2 | | | | |
| H 342-00 | FEB 23,1964 | 1600 | 15-24N | 152-40W | .048 | .010 | .021 | .020 | | | | | | | | |

| | | | | | BIOLOGICAL OBSERVATIONS | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | CHLOROPHYLL | | | CAROT | CARBON FIXATION | | | | ZOOPLANKTON | | | |
| STATION | DATE | TIME | LAT. | LONG. | *a* | *b* | *c* | CP | Dk | Lt′ | Lt | $\overline{Lt}$ | S-S | S-L | 20-S | 20-L |
| | | | | | $(mg/m^3)$ | | | (mSPU) | $(mg/m^3$-day) | | | | | | | |
| H 342-01 | FEB 23,1964 | 1810 | 15-42N | 153-02W | .080 | .023 | .041 | .030 | | | | | | | | |
| H 343-00 | FEB 23,1964 | 2000 | 15-57N | 153-13W | .059 | .021 | .026 | .026 | | | | | 95 | 0 | 78 | 0 |
| H 343-01 | FEB 24,1964 | 0005 | 16-21N | 153-31W | .032 | .010 | .000 | .018 | | | | | | | | |
| H 343-02 | FEB 24,1964 | 0310 | 16-53N | 153-56W | .041 | .013 | .024 | .019 | | | | | | | | |
| H 343-03 | FEB 24,1964 | 0625 | 17-12N | 154-11W | .050 | .024 | .030 | .022 | 2.0 | 4.2 | 4.9 | 4.6 | | | | |
| H 344-00 | FEB 24,1964 | 0800 | 17-27N | 154-21W | .068 | .024 | .038 | .027 | | | | | 4 | 0 | | |
| H 344-01 | FEB 24,1964 | 1215 | 17-58N | 154-46W | .053 | .016 | .024 | .022 | 1.9 | 2.1 | 1.6 | 1.8 | | | | |
| H 345-00 | FEB 24,1964 | 1810 | 18-44N | 155-30W | .054 | .022 | .039 | .026 | | | | | | | | |
| P 001-00 | MAR 02,1964 | 0545 | 21-26N | 161-56W | .042 | .034 | .049 | .048 | | | | | | | | |
| P 002-00 | MAR 02,1964 | 1000 | 21-33N | 162-41W | .035 | .029 | .047 | .032 | | | | | | | | |
| P 003-00 | MAR 02,1964 | 1150 | 21-34N | 163-02W | .039 | .043 | .054 | .031 | 2.9 | .3 | | .3 | | | | |
| P 004-00 | MAR 02,1964 | 1500 | 21-37N | 163-42W | .028 | .034 | .027 | .027 | | | | | | | | |
| P 005-00 | MAR 02,1964 | 1750 | 21-40N | 164-12W | .046 | .010 | .034 | .029 | | | | | | | | |
| P 006-00 | MAR 02,1964 | 2200 | 21-45N | 165-07W | .037 | .006 | .033 | .022 | | | | | | | | |
| P 007-00 | MAR 02,1964 | 2220 | 21-46N | 165-08W | .041 | .016 | .032 | .024 | | | | | | | | |
| P 008-00 | MAR 03,1964 | 0200 | 21-50N | 165-49W | .052 | .019 | .086 | .022 | | | | | | | | |
| P 009-00 | MAR 03,1964 | 0540 | 21-55N | 166-33W | .055 | .010 | .038 | .017 | 1.3 | 5.6 | 5.5 | 5.6 | | | | |
| P 010-00 | MAR 03,1964 | 0950 | 22-03N | 167-19W | .044 | .008 | .015 | .017 | | | | | | | | |
| P 011-00 | MAR 03,1964 | 1145 | 22-05N | 167-44W | .054 | .022 | .039 | .022 | 1.0 | 3.7 | 3.2 | 3.5 | | | | |
| P 012-00 | MAR 03,1964 | 1600 | 22-10N | 168-36W | .048 | .018 | .026 | .021 | | | | | | | | |
| P 013-00 | MAR 03,1964 | 1745 | 22-12N | 168-59W | .046 | .007 | .026 | .020 | | | | | | | | |
| P 014-00 | MAR 03,1964 | 2200 | 22-21N | 169-48W | .034 | .008 | .022 | .016 | | | | | | | | |
| P 015-00 | MAR 04,1964 | 0100 | 22-24N | 170-21W | .041 | .016 | .032 | .021 | | | | | | | | |
| P 016-00 | MAR 04,1964 | 0330 | 22-28N | 170-48W | .039 | .014 | .025 | .019 | | | | | | | | |
| P 017-00 | MAR 04,1964 | 0530 | 22-32N | 171-11W | .051 | .002 | .004 | .015 | 1.2 | 4.9 | 5.2 | 5.0 | | | | |
| P 018-00 | MAR 04,1964 | 1000 | 22-39N | 172-01W | .046 | .011 | .022 | .020 | | | | | | | | |
| P 019-00 | MAR 04,1964 | 1140 | 22-42N | 172-19W | .047 | .025 | .031 | .020 | 1.3 | 2.7 | 1.4 | 2.1 | | | | |
| P 020-00 | MAR 04,1964 | 1600 | 22-47N | 173-07W | .044 | .013 | .012 | .018 | | | | | | | | |
| P 021-00 | MAR 04,1964 | 1745 | 22-49N | 173-26W | .047 | .003 | .018 | .025 | | | | | | | | |
| P 022-00 | MAR 04,1964 | 2210 | 22-58N | 174-09W | .037 | .003 | .013 | .019 | | | | | | | | |
| P 023-00 | MAR 05,1964 | 0100 | 23-02N | 174-52W | .050 | .020 | .033 | .021 | | | | | | | | |
| P 025-00 | MAR 05,1964 | 0540 | 23-07N | 175-40W | .062 | .012 | .020 | .029 | 1.1 | 7.2 | 6.4 | 6.8 | | | | |
| P 026-00 | MAR 05,1964 | 0815 | 23-12N | 176-11W | .058 | .011 | .014 | .022 | | | | | | | | |
| P 027-00 | MAR 05,1964 | 1130 | 23-09N | 176-48W | .057 | .017 | .030 | .025 | 1.3 | 9.2 | 8.9 | 9.0 | | | | |
| P 028-00 | MAR 05,1964 | 1530 | 23-12N | 177-30W | .071 | .020 | .029 | .028 | | | | | | | | |
| P 029-00 | MAR 05,1964 | 1740 | 23-13N | 177-37W | .090 | .019 | .037 | .028 | | | | | | | | |
| P 030-00 | MAR 05,1964 | 2230 | 23-18N | 178-48W | .069 | .017 | .022 | .021 | | | | | | | | |
| P 031-00 | MAR 06,1964 | 0230 | 23-22N | 179-39W | .071 | .022 | .049 | .025 | | | | | | | | |
| P 032-00 | MAR 07,1964 | 0530 | 23-27N | 179-40E | .073 | .022 | .036 | .022 | 1.6 | 4.5 | 5.0 | 4.7 | | | | |
| P 033-00 | MAR 07,1964 | 0915 | 23-30N | 178-59E | .058 | .010 | .025 | .015 | | | | | | | | |
| P 034-00 | MAR 07,1964 | 1130 | 23-31N | 178-32E | .057 | .018 | .019 | .020 | 1.1 | 5.5 | 4.4 | 5.0 | | | | |
| P 035-00 | MAR 07,1964 | 1600 | 23-36N | 177-35E | .046 | .015 | .019 | .018 | | | | | | | | |
| P 036-00 | MAR 07,1964 | 1740 | 23-38N | 177-16E | .042 | .011 | .000 | .011 | | | | | | | | |
| P 037-00 | MAR 07,1964 | 2130 | 23-42N | 176-34E | .043 | .011 | .005 | .018 | | | | | | | | |
| P 038-00 | MAR 07,1964 | 2145 | 23-42N | 176-30E | .044 | .004 | .019 | .014 | | | | | | | | |
| P 039-00 | MAR 08,1964 | 0140 | 23-45N | 175-48E | .039 | .015 | .014 | .014 | | | | | | | | |
| P 040-00 | MAR 08,1964 | 0535 | 23-52N | 174-57E | .064 | .023 | .020 | .021 | 1.1 | 4.2 | 4.2 | 4.2 | | | | |
| P 041-00 | MAR 08,1964 | 0930 | 23-56N | 174-15E | .053 | .008 | .019 | .021 | | | | | | | | |
| P 042-00 | MAR 08,1964 | 1120 | 23-59N | 173-58E | .049 | .007 | .013 | .017 | 1.2 | 2.0 | 2.7 | 2.3 | | | | |
| P 043-00 | MAR 08,1964 | 1550 | 24-04N | 173-13E | .046 | .015 | .019 | .019 | | | | | | | | |
| P 044-00 | MAR 08,1964 | 1740 | 24-02N | 172-55E | .041 | .009 | .016 | .017 | | | | | | | | |
| P 045-00 | MAR 08,1964 | 2045 | 24-06N | 172-17E | .046 | .007 | .014 | .019 | | | | | | | | |
| P 046-00 | MAR 09,1964 | 0245 | 24-12N | 171-05E | .044 | .012 | .023 | .022 | | | | | | | | |
| P 047-00 | MAR 09,1964 | 0530 | 24-15N | 170-33E | .057 | .023 | .015 | .028 | 1.0 | 4.4 | 4.8 | 4.6 | | | | |

BIOLOGICAL OBSERVATIONS

| STATION | DATE | TIME | LAT. | LONG. | CHLOROPHYLL | | | CAROT | CARBON FIXATION | | | | ZOOPLANKTON | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | *a* | *b* | *c* | CP | Dk | Lt | Lt | L̄t | S-S | S-L | 20-S | 20-L |
| | | | | | | (mg/m$^3$) | | (mSPU) | | (mg/m$^3$-day) | | | | | | |
| P 048-00 | MAR 09,1964 | 0900 | 24-18N | 169-49E | .039 | .015 | .002 | .018 | | | | | | | | |
| P 049-00 | MAR 09,1964 | 1145 | 24-21N | 169-23E | .053 | .004 | .023 | .024 | 1.2 | 3.3 | 3.7 | 3.5 | | | | |
| P 050-00 | MAR 09,1964 | 1500 | 24-23N | 168-46E | .044 | .007 | .027 | .020 | | | | | | | | |
| P 051-00 | MAR 09,1964 | 1730 | 24-29N | 168-00E | .041 | .012 | .036 | .028 | | | | | | | | |
| P 052-00 | MAR 09,1964 | 2020 | 24-30N | 167-49E | .043 | .016 | .020 | .019 | | | | | | | | |
| P 053-00 | MAR 10,1964 | 0145 | 24-34N | 166-15E | .044 | .005 | .007 | .022 | | | | | | | | |
| P 054-00 | MAR 10,1964 | 0530 | 24-38N | 166-03E | .042 | .006 | .008 | .018 | 1.3 | 3.7 | 3.4 | 3.5 | | | | |
| P 055-00 | MAR 10,1964 | 0930 | 24-43N | 165-20E | .035 | .010 | .000 | .017 | | | | | | | | |
| P 056-00 | MAR 10,1964 | 1130 | 24-45N | 164-57E | .032 | .007 | .000 | .014 | 1.2 | 2.7 | 1.8 | 2.2 | | | | |
| P 057-00 | MAR 10,1964 | 1515 | 24-58N | 164-18E | .047 | .004 | .006 | .020 | | | | | | | | |
| P 058-00 | MAR 10,1964 | 1750 | 25-06N | 163-52E | .048 | .012 | .041 | .020 | | | | | | | | |
| P 059-00 | MAR 10,1964 | 2100 | 25-16N | 163-19E | .044 | .012 | .023 | .018 | | | | | | | | |
| P 060-00 | MAR 11,1964 | 0115 | 25-30N | 162-35E | .051 | .009 | .020 | .021 | | | | | | | | |
| P 061-00 | MAR 11,1964 | 0530 | 25-42N | 161-56E | .064 | .015 | .027 | .029 | .8 | 4.8 | 4.7 | 4.7 | | | | |
| P 062-00 | MAR 11,1964 | 0900 | 25-54N | 161-18E | .053 | .015 | .009 | .022 | | | | | | | | |
| P 063-00 | MAR 11,1964 | 1130 | 26-02N | 160-54E | .053 | .018 | .016 | .021 | 1.2 | .6 | .6 | .6 | | | | |
| P 064-00 | MAR 11,1964 | 1500 | 26-12N | 160-26E | .043 | .017 | .008 | .019 | | | | | | | | |
| P 065-00 | MAR 11,1964 | 1745 | 26-19N | 160-02E | .051 | .006 | .012 | .021 | | | | | | | | |
| P 066-00 | MAR 11,1964 | 2215 | 26-33N | 159-21E | .051 | .005 | .024 | .026 | | | | | | | | |
| P 067-00 | MAR 12,1964 | 0200 | 26-45N | 158-45E | .060 | .017 | .018 | .028 | | | | | | | | |
| P 068-00 | MAR 12,1964 | 0530 | 26-57N | 158-08E | .066 | .018 | .032 | .027 | 1.2 | 3.4 | 3.8 | 3.6 | | | | |
| P 069-00 | MAR 12,1964 | 0600 | 26-58N | 158-04E | .074 | .012 | .023 | .034 | | | | | | | | |
| P 070-00 | MAR 12,1964 | 0900 | 27-08N | 157-32E | .067 | .014 | .026 | .028 | | | | | | | | |
| P 071-00 | MAR 12,1964 | 1130 | 27-16N | 157-10E | .082 | .030 | .045 | .035 | 1.4 | 1.6 | 1.6 | 1.6 | | | | |
| P 072-00 | MAR 12,1964 | 1400 | 27-29N | 156-40E | .130 | .040 | .066 | .045 | | | | | | | | |
| P 073-00 | MAR 12,1964 | 1745 | 27-42N | 155-58E | .115 | .024 | .048 | .040 | | | | | | | | |
| P 074-00 | MAR 12,1964 | 2130 | 27-56N | 155-27E | .304 | .068 | .154 | .096 | | | | | | | | |
| P 075-00 | MAR 13,1964 | 0200 | 28-10N | 154-48E | .257 | .074 | .118 | .084 | | | | | | | | |
| P 076-00 | MAR 13,1964 | 0530 | 28-16N | 154-21E | .225 | .056 | .113 | .076 | 1.1 | 15.2 | | 15.2 | | | | |
| P 077-00 | MAR 13,1964 | 0830 | 28-28N | 153-50E | .227 | .061 | .140 | .082 | | | | | | | | |
| P 078-00 | MAR 13,1964 | 1130 | 28-38N | 153-23E | .243 | .067 | .134 | .086 | 1.3 | 1.4 | 1.7 | 1.6 | | | | |
| P 079-00 | MAR 13,1964 | 1445 | 28-50N | 152-52E | .293 | .090 | .175 | .105 | | | | | | | | |
| P 080-00 | MAR 13,1964 | 1745 | 28-59N | 152-23E | .331 | .081 | .199 | .116 | | | | | | | | |
| P 081-00 | MAR 13,1964 | 2130 | 29-10N | 151-56E | .318 | .091 | .189 | .111 | | | | | | | | |
| P 082-00 | MAR 14,1964 | 0100 | 29-26N | 151-17E | .256 | .081 | .134 | .082 | | | | | | | | |
| P 083-00 | MAR 14,1964 | 0530 | 29-42N | 150-32E | .338 | .101 | .198 | .111 | 1.1 | 23.7 | 26.7 | 25.2 | | | | |
| P 084-00 | MAR 14,1964 | 0845 | 29-58N | 149-56E | .293 | .084 | .159 | .103 | | | | | | | | |
| P 085-00 | MAR 14,1964 | 1130 | 30-13N | 149-29E | .513 | .145 | .282 | .170 | 1.4 | 27.0 | 25.1 | 26.1 | | | | |
| P 086-00 | MAR 14,1964 | 1445 | 30-28N | 148-56E | .347 | .146 | .186 | .101 | | | | | | | | |
| P 087-00 | MAR 14,1964 | 1745 | 30-41N | 148-31E | .329 | .133 | .188 | .099 | | | | | | | | |
| P 088-00 | MAR 14,1964 | 2330 | 30-50N | 147-52E | .240 | .076 | .140 | .073 | | | | | | | | |
| P 089-00 | MAR 15,1964 | 0530 | 31-07N | 147-05E | .274 | .091 | .167 | .082 | 1.1 | 21.5 | 24.2 | 22.9 | | | | |
| P 090-00 | MAR 15,1964 | 0945 | 31-22N | 146-22E | .249 | .079 | .152 | .078 | | | | | | | | |
| P 091-00 | MAR 15,1964 | 1130 | 31-31N | 146-08E | .292 | .090 | .187 | .085 | .9 | 4.0 | 4.0 | 4.0 | | | | |
| P 092-00 | MAR 15,1964 | 1530 | 31-54N | 145-32E | .306 | .105 | .176 | .093 | | | | | | | | |
| P 093-00 | MAR 15,1964 | 1745 | 32-07N | 145-12E | .310 | .115 | .175 | .089 | | | | | | | | |
| P 094-00 | MAR 15,1964 | 2050 | 32-23N | 144-34E | .539 | .174 | .325 | .160 | | | | | | | | |
| P 095-00 | MAR 16,1964 | 0100 | 32-43N | 143-52E | 1.098 | .250 | .750 | .391 | | | | | | | | |
| P 096-00 | MAR 16,1964 | 0515 | 33-03N | 143-13E | .342 | .088 | .207 | .109 | 1.8 | 22.5 | 20.7 | 21.6 | | | | |
| P 097-00 | MAR 16,1964 | 0845 | 33-15N | 142-37E | .374 | .089 | .214 | .116 | | | | | | | | |
| P 098-00 | MAR 16,1964 | 1130 | 33-26N | 142-15E | .235 | .072 | .157 | .066 | 2.2 | 7.1 | | 7.1 | | | | |

# APPENDIX D

## COMPUTATION AND INTERPOLATION OF HYDROGRAPHIC STATION DATA[1]

The equations which follow were used in the hydrographic station computations and interpolations. These equations and descriptions of computing methods are intended to serve only as a reference to techniques used in the calculations, and not as a detailed description of the computer program. All symbols not explained here have been explained in Appendix A.

**For observed depths** (McGill, 1961)

*Chlorinity*

$$\mathrm{Cl} = \frac{\mathrm{S} - 0.030}{1.8050}$$

*Potential density anomaly*

$$\sigma_{\mathrm{T}} = \Sigma_{\mathrm{T}} + (\sigma_0 + 0.1324)\ (1 - \mathrm{A_T} + \mathrm{B_T}\,[\sigma_0 - 0.1324])$$

where

$$\sigma_0 = -0.069 + 1.4708\mathrm{Cl} - 0.001570\mathrm{Cl}^2 + 0.0000398\mathrm{Cl}^3$$

$$\Sigma_{\mathrm{T}} = \frac{-(\mathrm{T} - 3.98)^2(\mathrm{T} + 283)}{503.57\ (\mathrm{T} + 67.26)}$$

$$\mathrm{A_T} = \mathrm{T}(4.7867 - 0.098185\mathrm{T} + 0.0010843\mathrm{T}^2)10^{-3}$$

$$\mathrm{B_T} = \mathrm{T}(18.030 - 0.8164\mathrm{T} + 0.01667\mathrm{T}^2)10^{-6}$$

*Thermosteric anomaly*

$$\delta_{\mathrm{T}} = \left(\frac{1}{1 + 0.001\sigma_{\mathrm{T}}} - 0.972643\right)10^5$$

*Apparent oxygen utilization*

$$\mathrm{AOU} = \mathrm{O_2'} - \mathrm{O_2}$$

where the oxygen solubility in ml/L (Truesdale *et al*, 1955) is
$\mathrm{O_2'} = 11.20\ (-2464\mathrm{T} + 48.21\mathrm{T}^2 - 0.4038\mathrm{T}^3 + 88506 - 525.6\mathrm{S} + 16\mathrm{ST} - 0.2338\mathrm{ST}^2)10^{-5}$

**For interpolated depths**

The water column is divided into at most three regions for interpolation. If there is a subsurface maximum of temperature or thermosteric anomaly, then region (1) exists, and extends from the surface to the depth of maximum temperature or thermosteric anomaly. Region (2) is between the depth of maximum temperature (usually the sea surface) and the mid-depth of the maximum observed temperature gradient. Region (3) is below this mid-depth.

The temperature gradient between each observed temperature and the next deepest one at the station is computed. Then the maximum gradient is determined, and for the corresponding depth interval the average depth, temperature, and thermosteric anomaly are found by linear interpolation. Apparent surface values are found by logarithmic extrapolation for either of two cases:

a) when surface temperature or salinity is missing, or

b) when maximum values of temperature or thermosteric anomaly are not at the surface.

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[1] Prepared by Edward B. Bennett and Christopher T. Psaropulos, Inter-American Tropical Tuna Commission.

## APENDICE D (Continued)

The equation used for the extrapolation is

$$\frac{d\ \ln(F_0 - F + 1)}{dZ} = k$$

which in approximation yields

$$F_0 = \frac{1}{2}\ (F_1 + F_2) + \frac{(F_1 + F_2) Z_2}{2\ (Z_2 - Z_1)}$$

where $F_0$ is the apparent surface temperature or thermosteric anomaly, and $F_1$ and $F_2$ are the observed values at $Z_1$ and $Z_2$, the depths nearest the sea surface.

Interpolation at standard depths that fall within regions (1) and (3) is according to the equation of the form

$$F - F_1 = \ln\left(\frac{Z + 1}{Z_1 + 1}\right)^k$$

In region (2) the equation used is

$$F = F_0 + 1 - e^{kZ}$$

After temperature and thermosteric anomaly are found, the potential density anomaly is then computed from thermosteric anomaly.

The preceding equation for $\delta_T$ is solved in terms of $\sigma_T$ and substituted in the $\sigma_T$ equation. This is a sixth-degree equation with salinity as the only unknown. The Newton-Raphson iteration method is used to capture the interpolated value of salinity using an initial guess of 35.00°/₀₀.

*Specific volume anomaly*

$$\delta = \left(\frac{1 - 10^{-10}P\mu}{1 + 10^{-4}\ \sigma_T} - 0.972643\ [1 - 10^{-10}P\mu_0]\right)10^5$$

where $\sigma_T$ is the potential volume anomaly at the standard depth, P is the pressure which is approximately numerically equal to the depth in meters, $\mu$ is the coefficient of isothermal compressibility and $\mu_0$ the coefficient of isothermal compressibility at 0 C. The compressibility correction per decibar is given by the formula

$$\begin{aligned}\mu = {} & \frac{4886}{1 + 1.83P10^{-5}} - 227 - T(28.33 - 0.551T + 0.004T^2) \\ & + P(105.5 + 9.50T - 0.158T^2)10^{-4} - 1.50P^2T\ 10^{-8} \\ & + \frac{\sigma_0 - 28}{10}\ [-147.3 + 2.72T - 0.04T^2 + P(32.4 - 0.87T + 0.02T^2)10^{-1}] \\ & + \left(\frac{\sigma_0 - 28}{10}\right)^2 [4.5 - 0.1T - P(1.8 - 0.06T)10^{-1}]\end{aligned}$$

*Dynamic height*

$$\Delta D_{Z/0} = \int_0^{P_Z} \delta\ d\ P \approx \sum_i \Delta Z_i \bar{\delta}_i$$

$$\Delta D_{Z/Z\max} = \int_{P_{\max}}^{P_Z} \delta\ d\ P$$

*Transport function*

$$Q_Z = \int_{Z_{\max}}^{Z} \Delta D\ d\ Z \approx \sum_i \Delta Z_i \Delta D_i$$

## APENDICE D

## COMPUTO E INTERPOLACION DE LOS DATOS DE LAS ESTACIONES HIDROGRAFICAS[1]

Se usaron las siguientes ecuaciones en los cómputos e interpolaciones de las estaciones hidrográficas. Estas ecuaciones y descripciones de los métodos de cómputo son solamente con el fin de servir como referencia a las técnicas usadas en los cálculos, y es una descripción detallada del programa del computador. Todos los símbolos que no se explican aquí, fueron explicados en el Apéndice A.

### Para las profundidades observadas (McGill, 1961)

*Clorinidad*

$$Cl = \frac{S - 0.030}{1.8050}$$

*Anomalía potencial de densidad*

$$\sigma_T = \Sigma_T + (\sigma_0 + 0.1324)\ (1 - A_T + B_T\,[\sigma_0 - 0.1324])$$

donde

$$\sigma_0 = -0.069 + 1.4708Cl - 0.001570Cl^2 + 0.0000398Cl^3$$

$$\Sigma_T = \frac{-(T - 3.98)^2(T + 283)}{503.57\ (T + 67.26)}$$

$$A_T = T(4.7867 - 0.098185T + 0.0010843T^2)10^{-3}$$

$$B_T = T(18.030 - 0.8164T + 0.01667T^2)10^{-6}$$

*Anomalía termostérica*

$$\delta_T = \left(\frac{1}{1 + 0.001\sigma_T} - 0.972643\right)10^5$$

*Utilización aparente de oxígeno*

$$AOU = O_2' - O_2$$

donde la solubilidad de oxígeno en m/L (Truesdale *et al*, 1955) es

$$O_2' = 11.20\ (-2464T + 28.21T^2 - 0.4038T^3 + 88506 - 525.6S + 16\ ST - 0.2338ST^2)10^{-5}$$

### Para las profundidades interpoladas

Para la interpolación, la columna de agua está dividida a lo más en tres regiones. Sí existe un máximum de temperatua en la subsuperficie o anomalía termostérica, entonces la región (1) existe, y se extiende de la superficie a la profundidad de la temperatura máxima o a la anomalía termostérica máxima. La Region (2) es entre la profundidad de la temperatura máxima (generalmente la superficie del mar) y la profundidad media del gradiente máximo observado de la temperatura. La Region (3) está debajo de esta profundidad media.

Se computa el gradiente de la temperatura entre cada temperatura observada y la próxima más profunda en la estación. Luego se determina el gradiente máximo, y por medio de la interpolación linear se encuentra el intervalo de profundidad correspondiente, el promedio de profundidad, la temperatura y la anomalía termostérica. Se hallan los valores aparentes de superficie por la extrapolación logarítmica para cualquiera de los dos casos:

a) cuando carece de la temperatura o salinidad de la superficie, o

b) cuando los valores máximos de temperatura o de la anomalía termostérica no están en la superficie.

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[1] Preparado por Edward B. Bennett y Christopher T. Psaropulos, Comisión Interamericana del Atún Tropical.

## APENDICE D (Continued)

Se usó la siguiente ecuación para la extrapolación:

$$\frac{d \ln (F_0 - F + 1)}{dZ} = k$$

lo que da en la aproximación

$$F_0 = \frac{1}{2} (F_1 + F_2) + \frac{(F_1 + F_2)\, Z_2}{2\,(Z_2 - Z_1)}$$

donde $F_0$ es la temperatura aparente de la superficie o la anomalía termostérica, y $F_1$ y $F_2$ son los valores observados en $Z_1$ y $Z_2$, las profundidades cerca de la superficie del mar.

La interpolación en las profundidades estándar que caen dentro de las regiones (1) y (3) está de acuerdo con la ecuación de la forma

$$F - F_1 = \ln \left( \frac{Z + 1}{Z_1 + 1} \right)^k$$

En la región (2) se usó la ecuación

$$F = F_0 + 1 - e^{kZ}$$

Después de haber hallado la temperatura y anomalía termostérica, se calcula la anomalía de densidad potencial de la anomalía termostérica.

La ecuación precedente para $\delta_T$ se resuelve como función de $\sigma_T$ y se substituye en la ecuación $\sigma_T$. Esta es una ecuación del sexto grado en la cual solamente la salinidad es desconocida. Se usa el método de iteración de Newton-Raphson para llegar al valor interpolado de salinidad usando una suposición inicial de $35.00\,^0/_{00}$.

*Anomalía del volumen específico*

$$\delta = \frac{1 - 10^{-10} P\mu}{1 + 10^{-4}\,\sigma_T} - 0.972643\ [1 - 10^{-10} P\mu_0]\ )10^5$$

donde $\sigma_T$ es la anomalía de volumen potencial en la profundidad estándar, P es la presión que es aproximadamente numéricamente igual a la profundidad en metros, $\mu$ es el coeficiente de la comprimibilidad isotermal y $\mu_0$ es el coeficiente de la comprimibilidad isotermal a 0 C. La corrección para la comprimibilidad por decibarra se da en la fórmula

$$\mu = \frac{4886}{1 + 1.83 P 10^{-5}} - 227 - T(28.33 - 0.551T + 0.004T^2)$$

$$+ P(105.5 + 9.50T - 0.158T^2)10^{-4} - 1.50P^2T\,10^{\backprime} +$$

$$\frac{\sigma_0 - 28}{10}\ [-147.3 + 2.72T - 0.04T^2 + P(32.4 - 0.87T + 0.02T^2)10^{-1}]$$

$$+ \left( \frac{\sigma_0 - 28}{10} \right)^2\ [4.5 - 0.1T - P(1.8 - 0.06T)10^{-1}]$$

*Altitud dinámica*

$$\Delta D_{Z\,0} = \int_0^{P_Z} \delta\, d\, P \approx \sum_i \Delta Z_i \bar{\delta}_i$$

$$\Delta D_{Z\,Z\max} = \int_{P_{\max}}^{P_Z} \delta\, d\, P$$

*Función de transporte*

$$Q_Z = \int_{Z_{\max}}^{Z} \Delta D\, d\, Z \approx \sum_i \Delta Z_i \Delta D_i$$

An important phase of the scientific work of the Inter-American Tropical Tuna Commission is the publication of research results. The Commission publishes studies by its staff and by cooperating scientists in its *Bulletin* series, in both English and Spanish.

The Commission also publishes, in these languages, the Annual Report of the Inter-American Tropical Tuna Commission. In the Annual Report are reported the actions of the Commission, a review of the year's work carried out under the direction of the Commission, a roster of scientific staff, and a listing of all publications issued during the preceding calendar year.

Bulletins, Annual Reports, and papers published by the staff in other journals are distributed on an exchange basis to a selected international list of governmental organizations, official libraries and laboratories and interested members of the scientific community. Requests for these publications, as well as for a listing of all publications, may be directed to The Editor.

Some recent publications in the *Bulletin* series are:

Una fase importante del trabajo científico de la Comisión Interamericana del Atún Tropical es la publicación de los resultados de sus investigaciones. La Comisión publica tanto en inglés como en español, los estudios efectuados por su personal y por científicos que cooperan en su serie de *Boletines.*

La Comisión también publica en estos idiomas, el Informe Anual de la Comisión Interamericana del Atún Tropical. En el Informe Anual, se participa sobre las acciones de la Comisión; una revisión del trabajo llevado a cabo durante el año bajo la dirección de la Comisión; un registro del personal científico y una lista de todas las publicaciones editadas durante el año calendario anterior.

Los *Boletines,* Informes Anuales y artículos publicados por el personal en otras revistas, se distribuyen, a base de intercambio, a una lista internacional escogida de organizaciones gubernamentales, bibliotecas oficiales, laboratorios y personas interesadas de la comunidad científica. Los pedidos para estas publicaciones, lo mismo que de la lista de todas las ediciones, deben ser dirigidos al Editor.

Las publicaciones recientes en la serie de *Boletines* son:

Vol. IX, No. 6

General review of the Japanese tuna long-line fishery in the eastern tropical Pacific Ocean 1956-1962, *by* Akira Suda and Milner B. Schaefer. La Jolla, 1965.

Revisión general de la pesquería japonesa con palangre del atún en el Océano Pacífico oriental tropical 1956-1962, *por* Akira Suda y Milner B. Schaefer. La Jolla, 1965.

Vol. IX, No. 7

A quantitative analysis of the phytoplankton of the Gulf of Panama II. On the relationship between $C^{14}$ assimilation and the diatom standing crop, *by* Theodore J. Smayda. La Jolla, 1965. (Con resumen en español.)

Vol. 10, No. 1

Estimations, from tagging experiments, of mortality rates and other parameters respecting yellowfin and skipjack tuna, *by* Bernard D. Fink. La Jolla, 1965.

Estimación de las tasas de mortalidad y otros parámetros del atún aleta amarilla y del barrilete mediante experimentos de marcación, *por* Bernard D. Fink. La Jolla, 1965.

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# Some Methods for Estimating Ocean Mortality of Pacific Salmon and Applications[1,2]

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## ABSTRACT

Three methods for estimating oceanic natural mortality rates of Pacific salmon under certain survival conditions are presented. Estimates of ocean mortality rates of Bristol Bay and Karluk sockeye are given. The mortality rate during the year immediately preceding the last 2 months of ocean life of Bristol Bay sockeye that migrated to sea as 3-freshwater fish in 1956 and returned as mature 3-ocean fish in 1959 is estimated to be 28.9%. The average ocean mortality rate during the penultimate year of life of 3-ocean Bristol Bay sockeye is estimated to be 19.5% for the years 1956–57 to 1960–61. The natural mortality rate during the third year of ocean life of 3-freshwater Karluk sockeye is estimated to be 28.2%. Corresponding estimates of average monthly instantaneous mortality rates are 0.028, 0.018, and 0.031, respectively.

## INTRODUCTION

An impressive number of papers on estimates of oceanic natural mortality rates of Pacific salmon has become available within recent years. Parker (1962, 1963) lists these papers in his substantial contributions to the knowledge of this important biological statistic. The purpose of this paper is to add to the knowledge of ocean mortality rates of salmon by presenting a few methods for estimating such rates and applying these methods to existing data.

## MATURITY SCHEDULE METHOD

### Derivation of Equations

Several important sockeye salmon runs of North America are composed almost entirely of fish that migrate to sea in their second or third year of life as 2- or 3-freshwater fish and spend 2 or 3 years in the ocean before returning to their natal streams as mature 2- or 3-ocean fish. I shall use a model that simulates survival conditions during a portion of the ocean life history of such salmon runs to illustrate the derivation of equations for estimating an oceanic natural mortality rate from data on maturity schedules and returns.

The seaward migration of 2- and 3-freshwater fish takes place in late May or early June. Approximately 2 years later, the survivors, known as 2-ocean fish, fall into one of four maturity-age categories: mature 4.2 fish, immature

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4.2 fish, mature 5.3 fish, and immature 5.3 fish. The first numeral represents the year of life of the fish, and the second numeral represents the year of life in which the fish migrated to sea.

The numbers of 2-ocean fish of the two freshwater age groups on May 1 of year $x$ at sea are represented by $N_{4.2}$ and $N_{5.3}$. The proportions of mature 2-ocean fish in the two freshwater age groups are denoted by $p_{4.2}$ and $p_{5.3}$. Thus, the numbers of mature and immature 2-ocean fish of the two freshwater age groups on May 1 of year $x$ at sea are represented as follows:

| Freshwater age group | Number of 2-ocean fish | |
|---|---|---|
| | *Mature* | *Immature* |
| 2 | $N_{4.2}\ p_{4.2}$ | $N_{4.2}\ (1-p_{4.2})$ |
| 3 | $N_{5.3}\ p_{5.3}$ | $N_{5.3}\ (1-p_{5.3})$ |

The mature 2-ocean fish return to their natal stream on July 1 of year $x$. The survival rates for the two freshwater age groups of mature 2-ocean fish between May 1 and July 1 of year $x$ are represented by $s_{m2}$ and $s_{m3}$. The returns of 2-freshwater, 2-ocean fish ($R_{4.2}$) and 3-freshwater, 2-ocean fish ($R_{5.3}$) on July 1 of year $x$ are as follows:

$$R_{4.2} = N_{4.2}\ p_{4.2}\ s_{m2} \tag{1}$$

and

$$R_{5.3} = N_{5.3}\ p_{5.3}\ s_{m3} \tag{2}$$

The immature 2-ocean fish spend an additional year at sea before returning to their natal stream as 3-ocean fish. The survival rates for the two freshwater age groups of immature 2-ocean fish between May 1 of year $x$ and May 1 of year $x + 1$ (at which time they are mature 3-ocean fish) are represented by $s_{i2}$ and $s_{i3}$. The numbers of surviving 2-freshwater, 3-ocean fish ($N_{5.2}$) and 3-freshwater, 3-ocean fish ($N_{6.3}$) on May 1 of year $x + 1$ are as follows:

$$N_{5.2} = N_{4.2}\ (1-p_{4.2})\ s_{i2}$$

and

$$N_{6.3} = N_{5.3}\ (1-p_{5.3})\ s_{i3}$$

The 3-ocean fish return to their natal stream on July 1 of year $x + 1$. The survival rate for 2-freshwater, 3-ocean fish between May 1 and July 1 of year $x + 1$ is assumed to be $s_{m2}$, the same as the survival rate for mature 2-freshwater, 2-ocean fish during the corresponding 2-month period in year $x$. The survival rate for 3-freshwater, 3-ocean fish between May 1 and July 1 of year $x + 1$ is assumed to be $s_{m3}$, the same as the survival rate for mature 3-freshwater, 2-ocean fish during the corresponding 2-month period in year $x$. These survival conditions are analogous to those simulated in Population

Models 1, 3, and 4 of my Karluk sockeye ocean mortality analysis (Fredin, MS, 1963).

The returns of 2-freshwater, 3-ocean fish ($R_{5.2}$) and 3-freshwater, 3-ocean fish ($R_{6.3}$) on July 1 of year $x + 1$ are as follows:

$$R_{5.2} = N_{4.2}\ (1-p_{4.2})\ s_{t2}\ s_{m2} \tag{3}$$

and

$$R_{6.3} = N_{5.3}\ (1-p_{5.3})\ s_{t3}\ s_{m3} \tag{4}$$

Dividing equation (3) by (1) and equation (4) by (2), we obtain

$$\frac{R_{5.2}}{R_{4.2}} = \frac{(1-p_{4.2})\ s_{t2}}{p_{4.2}} \tag{5}$$

and

$$\frac{R_{6.3}}{R_{5.3}} = \frac{(1-p_{5.3})\ s_{t3}}{p_{5.3}} \tag{6}$$

Equation (5) can be used to estimate $s_{t2}$ when data on returns of 4.2 and 5.3 fish and an estimate of $p_{4.2}$ are available. Similarly, equation (6) can be used to estimate $s_{t3}$ when data on returns of 5.3 and 6.3 fish and an estimate of $p_{5.3}$ are available.

## APPLICATION OF METHOD

Table I shows the numbers of 4.2, 5.3, 5.2, and 6.3 fish in the combined sockeye runs to the Naknek-Kvichak, Nushagak, Egegik, and Ugashik river systems in Bristol Bay, Alaska, between 1956 and 1961, and the numbers of 2- and 3-ocean sockeye in the combined run in 1962. For 5 of the first 6 years, other age groups of sockeye accounted for less than 1% of the total Bristol Bay sockeye runs. In 1959, other age groups accounted for approximately 3% of the total run. The age composition data that are available for 1962 indicate that less than 1% of the total run in that year was composed of fish of age groups other than 4.2, 5.3, 5.2, and 6.3. Thus, for all practical purposes, the Bristol Bay sockeye runs can be considered to be composed of fish of the same four age groups as in the model run used to derive equations (5) and (6).

The numbers of fish shown in Table I do not necessarily represent the total returns of Bristol Bay sockeye, since they do not include the catches of Bristol Bay sockeye by the Japanese gill net fishery in the North Pacific Ocean. Tagging and racial studies by Canadian, Japanese, and United States fisheries scientists (Hartt, 1962; Fukuhara *et al.*, 1962; Margolis, 1963; Mosher, 1963; INPFC, 1961, 1962, 1963a) have shown that Bristol Bay sockeye occur in considerable quantities in high seas areas where Japanese gill net fishing takes place. The precise number of Bristol Bay sockeye, mature or immature, taken by the high seas gill net fishery each year is not known. Available data indicate only that in some years several million Bristol Bay sockeye are caught on the high seas.

TABLE I. Numbers of 4.2, 5.3, 5.2, and 6.3 fish in the Bristol Bay sockeye runs, 1956–61, and numbers of 2- and 3-ocean fish in the 1962 run. (All figures in millions of fish. Data for 1956–61 from Documents 491 and 602, International North Pacific Fisheries Commission; data for 1962 from Alaska Department of Fish and Game, Fisheries Research Institute, University of Washington, and Bureau of Commercial Fisheries, U.S. Fish and Wildlife Service.)

| Year | Size of run | | | | | | |
|---|---|---|---|---|---|---|---|
| | Age group | | Subtotal | Age group | | Subtotal | Total |
| | 4.2 | 5.3 | 2-ocean fish | 5.2 | 6.3 | 3-ocean fish | |
| 1956 | 12.105 | 8.472 | 20.577 | 2.385 | 1.604 | 3.989 | 24.566 |
| 1957 | 0.430 | 2.261 | 2.691 | 6.367 | 2.086 | 8.453 | 11.144 |
| 1958 | 1.346 | 1.485 | 2.831 | 1.310 | 1.334 | 2.644 | 5.475 |
| 1959 | 4.506 | 5.513 | 10.019 | 1.071 | 0.787 | 1.858 | 11.877 |
| 1960 | 30.285 | 1.732 | 32.017 | 2.590 | 1.322 | 3.912 | 35.929 |
| 1961 | 1.405 | 6.445 | 7.850 | 9.894 | 0.485 | 10.379 | 18.229 |
| 1962 | a | a | 7.000 | a | a | 3.147 | |

aIncomplete data

In such years, of course, the numbers of fish in the runs to Bristol Bay are considerably less than they would be if none of the sockeye had been caught on the high seas.

Statistical yearbooks of the International North Pacific Fisheries Commission (1956–62) list the Japanese high seas gill net catches of sockeye by 5-degree intervals of longitude and month of fishing. For the years 1956–60, Manzer *et al.* (MS, 1963) present age composition data, by monthly periods, for sockeye taken by the high seas gill net fishery east of 170° E long. Their age composition data are shown here in Table II.

Age composition data shown in Table II and catch statistics from the INPFC statistical yearbooks are used to estimate the Japanese high seas gill net catches of 4.2, 5.3, 5.2, and 6.3 sockeye in various areas of the North Pacific Ocean during various months for the years 1956–62. Average percentage age composition data for 1956–60 are used for compiling the high seas catches by age groups for 1961 and 1962. The compilation is shown in Table III.

Judging from data on migration rates of Bristol Bay sockeye (INPFC, 1961, app. 1, fig. 16) and the results of tagging and racial studies referred to previously, the areas and months for which catch statistics are shown in Table III probably represent the principal locations and times that mature Bristol Bay sockeye are caught by the Japanese high seas gill net fishery.

The catch statistics given in Table III indicate that, in 1958, small numbers of 2-ocean sockeye were caught by the high seas gill net fishery in the areas and months listed. The data also indicate that, in 1959, the high seas catches of

TABLE II. Estimated percentage age composition of sockeye caught by the Japanese high seas gill net fishery east of 170° E long, by month. (Data from Manzer *et al.*, MS, 1963.)

| Year | Month | Age group |  | Sub-total 2-ocean | Age group |  | Sub-total 3-ocean | Total | Other age groups |
|---|---|---|---|---|---|---|---|---|---|
|  |  | 4.2 | 5.3 |  | 5.2 | 6.3 |  |  |  |
| 1956 | May | 13 | 28 | 41 | 21 | 30 | 51 | 92 | 8 |
|  | June | 24 | 34 | 58 | 15 | 21 | 36 | 94 | 6 |
|  | July | 24 | 41 | 65 | 14 | 14 | 28 | 93 | 7 |
| 1957 | May | 1 | 15 | 16 | 38 | 41 | 79 | 95 | 6 |
|  | June | 2 | 22 | 24 | 40 | 32 | 72 | 96 | 4 |
|  | July | 8 | 27 | 35 | 30 | 29 | 59 | 94 | 6 |
| 1958 | May | 2 | 13 | 15 | 20 | 51 | 71 | 86 | 14 |
|  | June | 6 | 35 | 41 | 17 | 28 | 45 | 86 | 14 |
|  | July | – | – | – | – | – | – | – | – |
|  | Aug. | 25 | 53 | 78 | 7 | 6 | 13 | 91 | 9 |
| 1959 | May | 6 | 22 | 28 | 19 | 34 | 53 | 81 | 19 |
|  | June | 13 | 42 | 55 | 11 | 18 | 29 | 84 | 16 |
|  | July | 23 | 50 | 73 | 7 | 7 | 14 | 87 | 13 |
| 1960 | May | 10 | 16 | 26 | 31 | 31 | 62 | 88 | 12 |
|  | June | 43 | 11 | 54 | 16 | 25 | 41 | 95 | 5 |
|  | July | 27 | 50 | 77 | 5 | 11 | 16 | 93 | 7 |
|  | Aug. | 27 | 66 | 93 | 2 | 3 | 5 | 98 | 2 |
| Averages: 1956–60 | May | 6.4 | 18.8 | 25.2 | 25.8 | 37.4 | 63.2 | 88.4 |  |
|  | June | 17.6 | 28.8 | 46.4 | 19.8 | 24.8 | 44.6 | 91.0 |  |
|  | July | 20.5 | 42.0 | 62.5 | 14.0 | 15.2 | 29.2 | 91.7 |  |
|  | Aug. | 26.0 | 59.5 | 85.5 | 4.5 | 4.5 | 9.0 | 94.5 |  |

3-ocean sockeye were relatively small. If it is assumed that negligible numbers of 2-ocean Bristol Bay sockeye were caught on the high seas in 1958, and also that negligible numbers of 3-ocean Bristol Bay sockeye were caught offshore in 1959, the runs of these two ocean age groups to Bristol Bay in 1958 and 1959, respectively, can be considered to represent the total returns. Under these conditions, data on the sizes of the Bristol Bay runs of 2-ocean fish in 1958 and 3-ocean fish in 1959 can be used for estimating ocean survival and mortality rates from equation (5) or (6).

To use equation (5) or (6) to estimate ocean survival and mortality rates for Bristol Bay sockeye, it is necessary to assign values to the proportions of 2-ocean (4.2 or 5.3) Bristol Bay fish that matured in 1958. To my knowledge, there are no estimates available for the proportions of Bristol Bay sockeye that matured as 2-ocean fish in 1958 or any other year. In this circumstance, I will use certain maturity schedule data for Karluk sockeye (Fredin, MS, 1963) to represent the maturity schedules of Bristol Bay sockeye.

As indicated previously, the survival conditions which I assumed in deriving equations (5) and (6) are analogous to those simulated by Population Models 1, 3, and 4 in my Karluk sockeye study. In that study, Population Model 1

TABLE III. Estimated catches of 4.2, 5.3, 5.2, and 6.3 sockeye by the Japanese gill net fishery in various areas and months of fishing in the North Pacific Ocean. (Data from INPFC statistical yearbooks and Manzer *et al.*, MS, 1963.)

| Area | Months | Year | Catch in millions of fish | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | Age group | | Sub-total 2-ocean fish | Age group | | Sub-total 3-ocean fish | Total |
| | | | 4.2 | 5.3 | | 5.2 | 6.3 | | |
| 175° W to 180° | June–July | 1956 | 0.183 | 0.279 | 0.462 | 0.112 | 0.142 | 0.254 | 0.716 |
| | | 1957 | 0.056 | 0.588 | 0.644 | 1.060 | 0.851 | 1.911 | 2.555 |
| | | 1958 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | 1959 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | 1960 | 1.134 | 0.326 | 1.460 | 0.418 | 0.655 | 1.073 | 2.533 |
| | | 1961 | 0.765 | 1.252 | 2.017 | 0.861 | 1.079 | 1.940 | 3.957 |
| | | 1962 | 0.031 | 0.051 | 0.082 | 0.035 | 0.044 | 0.079 | 0.161 |
| 180° to 175° E | May–June | 1956 | 0.365 | 0.567 | 0.932 | 0.295 | 0.416 | 0.711 | 1.643 |
| | | 1957 | 0.047 | 0.518 | 0.565 | 0.952 | 0.772 | 1.724 | 2.289 |
| | | 1958 | 0 | 0.002 | 0.002 | 0.003 | 0.009 | 0.012 | 0.014 |
| | | 1959 | 0.038 | 0.123 | 0.161 | 0.032 | 0.053 | 0.085 | 0.246 |
| | | 1960 | 0.405 | 0.104 | 0.509 | 0.151 | 0.236 | 0.387 | 0.896 |
| | | 1961 | 0.132 | 0.216 | 0.348 | 0.148 | 0.185 | 0.333 | 0.681 |
| | | 1962 | 0.070 | 0.115 | 0.185 | 0.080 | 0.101 | 0.181 | 0.366 |
| 175° E to 170° E | May | 1956 | 0.112 | 0.241 | 0.353 | 0.181 | 0.258 | 0.439 | 0.792 |
| | | 1957 | 0.020 | 0.292 | 0.312 | 0.741 | 0.800 | 1.541 | 1.853 |
| | | 1958 | 0.011 | 0.074 | 0.085 | 0.113 | 0.289 | 0.402 | 0.487 |
| | | 1959 | 0.023 | 0.085 | 0.108 | 0.073 | 0.131 | 0.204 | 0.312 |
| | | 1960 | 0.021 | 0.033 | 0.054 | 0.064 | 0.064 | 0.128 | 0.182 |
| | | 1961 | 0.035 | 0.103 | 0.138 | 0.141 | 0.204 | 0.345 | 0.483 |
| | | 1962 | 0.028 | 0.082 | 0.110 | 0.113 | 0.164 | 0.277 | 0.387 |
| Totals | | 1956 | 0.660 | 1.087 | 1.747 | 0.588 | 0.816 | 1.404 | 3.151 |
| | | 1957 | 0.123 | 1.398 | 1.521 | 2.753 | 2.423 | 5.176 | 6.697 |
| | | 1958 | 0.011 | 0.076 | 0.087 | 0.116 | 0.298 | 0.414 | 0.501 |
| | | 1959 | 0.061 | 0.208 | 0.269 | 0.105 | 0.184 | 0.289 | 0.558 |
| | | 1960 | 1.560 | 0.463 | 2.023 | 0.633 | 0.955 | 1.588 | 3.611 |
| | | 1961 | 0.932 | 1.571 | 2.503 | 1.150 | 1.468 | 2.618 | 5.121 |
| | | 1962 | 0.129 | 0.248 | 0.377 | 0.228 | 0.309 | 0.537 | 0.914 |

simulates a constant monthly instantaneous mortality rate throughout ocean life. In Population Model 3, it is assumed that the instantaneous mortality rate is greatest during the first month of ocean residence, decreases geometrically (by a factor of 0.5) during each of the next 5 months of ocean life, and remains constant during the sixth and each succeeding month of ocean life. Population Model 4 simulates a catastrophic, age-specific first-month instantaneous mortality rate and a constant age-independent mortality rate in the second and succeeding months of ocean residence.

Using Population Models 1, 3, 4 and the releases and returns of seven groups of 3-freshwater Karluk sockeye marked as smolts in the late 1920's and early 1930's (Barnaby, 1944), the estimated average percentages of 3-freshwater Karluk sockeye that mature as 1- and 2-ocean fish are as follows (Fredin, MS, 1963, tables 6, 14, and 18):

| Population model | Estimated average per cent maturing | |
|---|---|---|
| | *1-ocean fish* | *2-ocean fish* |
| 1 | 1.35 | 51.41 |
| 3 | 2.35 | 59.78 |
| 4 | 2.11 | 57.30 |

Adjusting for the small proportions of sockeye that mature as 1-ocean fish (equation 15 of Fredin, MS, 1963), the estimated average percentages of 3-freshwater, 2-ocean Karluk sockeye at sea that mature as 2-ocean fish are as follows: Population Model 1—52.1%; Population Model 3—61.2%; and Population Model 4—58.5%. The mean of these three averages is 57.3%.

Using 57.3% as the proportion of the 3-freshwater, 2-ocean Bristol Bay sockeye at sea on May 1 of 1958 that returned to Bristol Bay as 2-ocean fish in 1958, we estimate $s_{i3}$ from equation (6) as follows:

$$R_{5.3\ (1958)} = 1.485 \text{ million fish; } R_{6.3\ (1959)} = 0.787 \text{ million fish;}$$

$$s_{i3} = \frac{0.787\ (0.573)}{1.485\ (1-0.573)} = 0.711$$

The estimated survival rate of 0.711 is equivalent to an instantaneous ocean mortality rate of approximately 0.34 for the 12-month period from May 1, 1958, to May 1, 1959. The estimated average monthly instantaneous ocean mortality rate during this period is approximately 0.028.

## OCEAN IMMATURES METHOD

### DERIVATION OF EQUATIONS

To illustrate the derivation of equations for estimating an oceanic natural mortality rate of a salmon run from indices of abundance of immature fish at sea and returns of mature fish, I shall use as a model a sockeye run whose members spend either 2 or 3 years in the ocean before returning to their natal stream as mature fish.

A seaward migration of smolts is considered to take place on June 1 of year 1. Fourteen months later — that is, on August 1 of year 2 — the survivors are immature 1-ocean fish. Their abundance at that time is $N_{1.2}$ (the first numeral in the subscript represents the ocean age of the fish, and the second numeral represents the calendar year). Approximately 8 months later, or 22 months after their seaward migration, the survivors are 2-ocean fish. Many of the 2-ocean fish mature and return to their natal stream on July 1 of year 3, 25 months after the beginning of ocean life.

Denoting the proportion of the $N_{1.2}$ fish that mature as 2-ocean sockeye by $p_{1.2}$, and their survival rate between August 1 of year 2 and July 1 of year 3 by $s$, the return, $R_{2.3}$, of mature 2-ocean sockeye on July 1 of year 3 is as follows:

$$R_{2.3} = N_{1.2}\ p_{1.2}\ s. \qquad (7)$$

The immature 2-ocean fish remain at sea where, on August 1 of year 3 (or 26 months following their seaward migration), their abundance is $N_{2.3}$. The quantity $N_{2.3}$ is equivalent to $N_{1.2}\,(1 - p_{1.2})\,s_o$, where $(1 - p_{1.2})$ is the proportion of the $N_{1.2}$ sockeye that do not mature as 2-ocean fish, and $s_o$ is the survival rate between August 1 of year 2 and August 1 of year 3 for the $N_{1.2}\,(1 - p_{1.2})$ fish. The quantity, $s_o$, is referred to as the survival rate during the penultimate year of life of 3-ocean sockeye.

In the spring of year 4, the survivors are 3-ocean fish. All of the 3-ocean fish mature and return to their natal stream on July 1 of year 4, 37 months after the beginning of ocean residence. Denoting the survival rate between August 1 of year 3 and July 1 of year 4 by $s$, the return, $R_{3.4}$, of 3-ocean fish on July 1 of year 4 is as follows:

$$\begin{aligned} R_{3.4} &= N_{2.3}\ s \\ &= N_{1.2}\ (1 - p_{1.2})\ s_o\ s. \qquad (8) \end{aligned}$$

In addition to the immature 2-ocean fish at sea on August 1 of year 3, there is also present a number of immature 1-ocean fish. The latter are survivors from the smolt migration that takes place on June 1 of year 2. Their abundance on August 1 of year 3 is $N_{1.3}$.

The return, $R_{2.4}$, of mature 2-ocean fish on July 1 of year 4 is as follows:

$$R_{2.4} = N_{1.3}\ p_{1.3}\ s \qquad (9)$$

where $p_{1.3}$ is the proportion of the $N_{1.3}$ fish that mature as 2-ocean sockeye, and $s$ is the survival rate between August 1 of year 3 and July 1 of year 4.

The abundance of immature 2-ocean fish on August 1 of year 4 is $N_{2.4}$. These are survivors from the smolt migration of June 1 of year 2. Their abundance is equivalent to $N_{1.3}\ (1 - p_{1.3})\ s_o$, where $s_o$ is the survival rate between August 1 of year 3 and August 1 of year 4 for the $N_{1.3}\ (1 - p_{1.3})$ fish.

The return, $R_{3.5}$, of 3-ocean fish on July 1 of year 5 is as follows:

$$\begin{aligned} R_{3.5} &= N_{2.4}\ s \\ &= N_{1.3}\ (1 - p_{1.3})\ s_o\ s \qquad (10) \end{aligned}$$

where $s$ is the survival rate between August 1 of year 4 and July 1 of year 5.

Dividing equation (9) by (8) and transposing terms, we obtain

$$p_{1.3} = \frac{R_{2.4}}{R_{3.4}}\,\frac{N_{2.3}}{N_{1.3}}\,. \qquad (11)$$

Dividing equation (10) by (9) and transposing terms, we obtain

$$s_o = \frac{R_{3.5}\ p_{1.3}}{R_{2.4}\ (1 - p_{1.3})}\,. \qquad (12)$$

If we have indices of abundance of immature 1- and 2-ocean fish at sea on August 1 of year 3, such that $I_{1.3} = kN_{1.3}$ and $I_{2.3} = kN_{2.3}$, equation (11) can be expressed as follows:

$$p_{1.3} = \frac{R_{2.4}}{R_{3.4}} \frac{I_{2.3}}{I_{1.3}}. \tag{13}$$

The equivalent of $p_{1.3}$ can be used in equation (12) to estimate $s_o$.

In this model, the survival rate during the last 11 months of ocean life of mature fish is assumed to be constant from year to year and the same for 2- and 3-ocean sockeye.

## APPLICATION OF METHOD

If it is assumed that all 4.2 and 5.3 sockeye (2-ocean fish) and all 5.2 and 6.3 sockeye (3-ocean fish) taken by the Japanese high seas gill net fishery between 170° E and 175° E in May, between 175° E and 180° in May and June, and between 180° and 175° W in June and July are mature Bristol Bay fish, we can add the catch statistics of Tables I and III to obtain estimates of the total returns of 2- and 3-ocean Bristol Bay sockeye ($R_2$ and $R_3$) between 1956 and 1962. These estimates are given in Table IV.

Tagging studies conducted by the Fisheries Research Institute, University of Washington, since 1956 in the North Pacific Ocean south of Adak Island have shown that immature 1- and 2-ocean Bristol Bay sockeye occur there during the months of July and August (Hartt, 1962; INPFC, 1956–61). Fishing by purse seine vessels to capture salmon for tagging south of Adak Island has also provided annual indices of abundance (average catch per seine set) of immature 1- and 2-ocean sockeye occurring there. These indices of abundance,

TABLE IV. Estimated total returns of 2- and 3-ocean Bristol Bay sockeye, 1956–62. (Data from Tables I and III.)

| Year | Return (millions of fish) | | |
|---|---|---|---|
| | 2-ocean (4.2 and 5.3) $R_2$ | 3-ocean (5.2 and 6.3) $R_3$ | Total |
| 1956 | 22.324 | 5.393 | 27.717 |
| 1957 | 4.212 | 13.629 | 17.841 |
| 1958 | 2.918 | 3.058 | 5.976 |
| 1959 | 10.288 | 2.147 | 12.435 |
| 1960 | 34.040 | 5.500 | 39.540 |
| 1961 | 10.353 | 12.997 | 23.350 |
| 1962 | 7.377 | 3.684 | 11.061 |

TABLE V. Average catch per seine set of immature sockeye south of Adak Island, 1956–62.

| Year | Average catch per set (no. of fish) | |
|---|---|---|
| | Immature 1-ocean sockeye $I_1$ | Immature 2-ocean sockeye $I_2$ |
| 1956 | 16.4 | 29.2 |
| 1957 | 4.3 | 1.7 |
| 1958 | 38.7 | 3.3 |
| 1959 | 126.1 | 14.5 |
| 1960 | 12.9 | 28.6 |
| 1961 | 19.7 | 4.1 |
| 1962 | 20.4 | 10.4 |

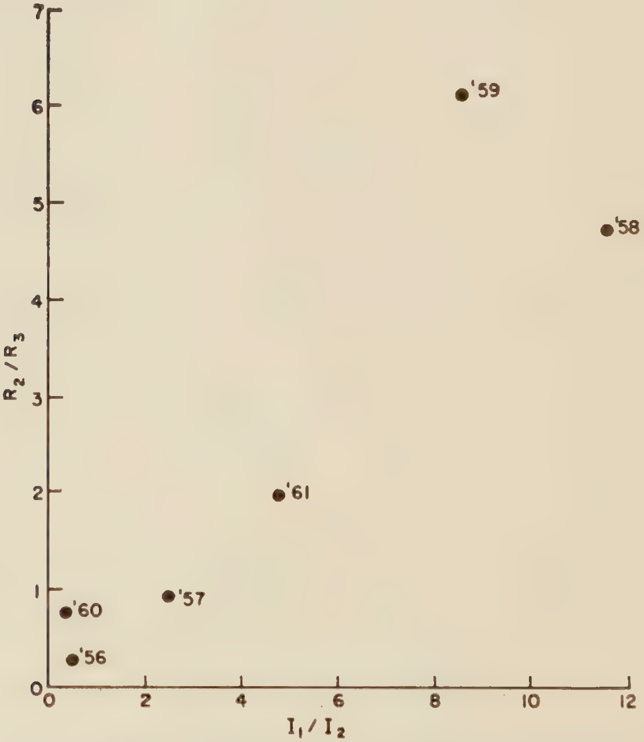

FIG. 1. Relation between ratio of estimated returns of 2- and 3-ocean Bristol Bay sockeye ($R_2/R_3$) and ratio of relative abundance of immature 1- and 2-ocean sockeye at sea in preceding year ($I_1/I_2$). (Year at sea indicated.)

TABLE VI. Ratios of relative abundance of immature 1- and 2-ocean sockeye south of Adak Island, 1956–61, and ratios of estimated returns of 2- and 3-ocean Bristol Bay sockeye, 1957–62.

| Year at sea | Ratio of relative abundance $I_1/I_2$ | Year of return | Ratio of estimated returns $R_2/R_3$ |
|---|---|---|---|
| 1956 | 0.56 | 1957 | 0.31 |
| 1957 | 2.53 | 1958 | 0.95 |
| 1958 | 11.73 | 1959 | 4.79 |
| 1959 | 8.70 | 1960 | 6.19 |
| 1960 | 0.45 | 1961 | 0.80 |
| 1961 | 4.80 | 1962 | 2.00 |

$I_1$ and $I_2$, respectively, are given in Alaska Department of Fish and Game (1963, table 8), and are shown here in Table V.

The ratios of relative abundance of immature 1- and 2-ocean sockeye for the years 1956–61 and the ratios of estimated returns of 2- and 3-ocean Bristol Bay sockeye for the years 1957–62 are shown in Table VI, and are plotted in Fig. 1.

The relation between $R_2/R_3$ and $I_1/I_2$ is clearly positive and, statistically, is significant at about the 1% confidence level ($r$, the correlation cœfficient, equals 0.91). The relation indicates that the indices of abundance of immature 1- and 2-ocean sockeye obtained by purse seine fishing south of Adak Island in the summer are representative of the relative numbers of immature 1- and 2-ocean Bristol Bay sockeye at sea on August 1, and can be used to estimate ocean survival of Bristol Bay sockeye from equations (13) and (12).

The variation of the relation between $R_2/R_3$ and $I_1/I_2$ is probably largely due to year-to-year changes in the availability of immature 1- and 2-ocean Bristol Bay sockeye to the purse seine vessels fishing south of Adak Island, differences in the fishing efficiency of purse seines from year to year, and fluctuations in the abundance of other sockeye stocks south of Adak Island. Because of the variation that exists, I will use average annual indices of abundance of immature 1- and 2-ocean sockeye south of Adak Island and average annual returns of 2- and 3-ocean Bristol Bay sockeye, rather than data for individual years, to estimate a survival rate for 3-ocean Bristol Bay sockeye during the 12 months immediately preceding their last 11 months of ocean life.

The average annual catches per seine set of immature 1- and 2-ocean sockeye south of Adak Island for the 5 years from 1956 to 1960 were 39.68 and 15.46 fish, respectively (Table V). The estimated average annual returns of 2- and 3-ocean Bristol Bay sockeye between 1957 and 1961 were 12.362 and

7.466 million fish, respectively (Table IV). The estimated average annual return of 3-ocean Bristol Bay sockeye between 1958 and 1962 was 5.477 million fish (Table IV).

Using the average annual indices of abundance of immature 1- and 2-ocean sockeye south of Adak Island between 1956 and 1960, and the estimated average annual returns of 2- and 3-ocean Bristol Bay sockeye between 1957 and 1961, we obtain an estimate of the average proportion of Bristol Bay sockeye that matured as 2-ocean fish in the years 1957–61 from equation (13) as follows:

$$\text{Av. } p_{1\ (1956\text{–}60)} = \left(\frac{12.362}{7.466}\right)\left(\frac{15.46}{39.68}\right) = 0.645.$$

Putting the estimate of 0.645 in equation (12), together with the estimated average annual returns of 2-ocean Bristol Bay sockeye between 1957 and 1961 and of 3-ocean Bristol Bay sockeye between 1958 and 1962, we obtain an estimate of the average annual survival rate during the penultimate year of life of 3-ocean Bristol Bay sockeye for the years 1956–57 to 1960–61. The estimate is as follows:

$$\text{Av. } s_{o\ (1956\text{–}57 \text{ to } 1960\text{–}61)} = \left(\frac{5.477}{12.362}\right)\left(\frac{0.645}{0.355}\right) = 0.805.$$

The estimated average annual survival rate during the penultimate year of life of 3-ocean Bristol Bay sockeye is equivalent to an instantaneous mortality rate of approximately 0.22. The corresponding average monthly instantaneous mortality rate is approximately 0.018.

## SMOLT INDICES METHOD

### DERIVATION OF EQUATIONS

I shall use a salmon run whose members have an ocean life span of 2 or 3 years as a model for deriving equations for estimating oceanic natural mortality rates from indices of smolt abundance and returns of 2- and 3-ocean fish.

The number of smolts migrating to sea in any year, $x$, is represented by $N_x$. It is assumed that an index of abundance of smolts is obtained for each seaward migration such that $I_x = kN_x$.

The survival rate during the first 2 years of ocean life, that is, from the time of seaward migration to the time of return of mature 2-ocean fish, is $s$. The proportion of smolts that mature as 2-ocean fish is $p_x$. The return, $R_{2x}$, of 2-ocean fish is as follows:

$$R_{2x} = N_x p_x \, s. \tag{14}$$

The survival rate during the third year of ocean life for those fish that spend 3 years at sea before returning to their natal stream is $s'$. The return, $R_{3x}$, of 3-ocean fish is as follows:

$$\begin{aligned} R_{3x} &= N_x\ (1 - px)\ s\ s' \qquad (15) \\ &= N_x\ s\ s' - N_x\, p_x\ s\ s' \\ &= N_x\ s\ s' - R_{2x}\ s'. \end{aligned}$$

Substituting $I_x/k$ for $N_x$ in equation (15), we obtain

$$R_{3x} = \frac{I_x}{k}\ s\ s' - R_{2x}\ s'. \qquad (16)$$

Dividing both sides by $I_x$, we obtain,

$$\frac{R_{3x}}{I_x} = \frac{s\ s'}{k} - \frac{R_{2x}}{I_x}\ s'. \qquad (17)$$

Equation (17) is linear in form. The slope of the line is $s'$ and the intercept is $ss'/k$. Assuming that $s$ and $s'$ are constant and provided that data on relative abundance of smolts and returns of 2- and 3-ocean fish are available for a series of years, equation (17) can be used to estimate $s'$ by linear regression methods. A measure of $k$, of course, would also permit an estimate to be made of $s$.

## APPLICATION OF METHOD

I will use a portion of the data presented by Barnaby (1944) on the releases and returns of marked Karluk sockeye to illustrate an application of equation (17) for estimating ocean mortality rates of a salmon run.

Practically all of the members of six groups (Group No. 5, 9, 13, 16, 19, and 23 as shown in table 3 of Fredin, MS, 1963) of 3-freshwater Karluk sockeye marked by Barnaby returned to Karluk River after 2 or 3 years of ocean residence. The releases and returns of these groups are as follows:

| Group No. | Number of smolts marked | Estimated returns (number of fish) | | | |
|---|---|---|---|---|---|
| | | 1-ocean $R_1$ | 2-ocean $R_2$ | 3-ocean $R_3$ | 4-ocean $R_4$ |
| 5 | 14,676 | 28 | 1,730 | 725 | 0 |
| 9 | 14,923 | 42 | 1,587 | 808 | 17 |
| 13 | 41,403 | 39 | 3,845 | 4,857 | 46 |
| 16 | 6,275 | 13 | 833 | 339 | 11 |
| 19 | 9,381 | 0 | 1,256 | 926 | 45 |
| 23 | 25,394 | 7 | 3,208 | 1,441 | 0 |

Assuming that 10% of the marked fish represents the indices of abundance of smolts in the six groups, and ignoring the returns of 1- and 4-ocean fish, the indices of abundance of smolts and the variables used in a regression analysis are as follows:

| $I_x$ | $R_{2x}/I_x$ | $R_{3x}/I_x$ |
|---|---|---|
| 1468 | 1.18 | 0.49 |
| 1492 | 1.06 | 0.54 |
| 4140 | 0.93 | 1.17 |
| 628 | 1.33 | 0.54 |
| 938 | 1.34 | 0.99 |
| 2539 | 1.26 | 0.57 |

The regression of $R_{3x}/I_x$ on $R_{2x}/I_x$ is given by the equation,

$$\frac{R_{3x}}{I_x} = 1.494 - 0.657\,\frac{R_{2x}}{I_x}.$$

The slope, 0.657, represents the survival rate during the third year of ocean life of marked 3-freshwater Karluk sockeye that mature as 3-ocean fish. This rate corresponds to an instantaneous mortality rate of approximately 0.42. Adjusting for the effects of marking after the manner of Ricker (1962), that is, dividing 0.42 by 1.27, the instantaneous mortality rate of unmarked fish is estimated to be 0.33. The estimated ocean survival rate of unmarked fish is approximately 71.8%. Using 10.67 months as the duration of the third year of ocean life of 3-freshwater Karluk sockeye (table 2 of Fredin, MS, 1963), the average monthly instantaneous mortality rate is estimated to be 0.031.

The intercept, 1.494, represents the product of the survival rates during the first 2 years and third year of ocean residence divided by the proportion (10%) of the smolt migrations represented by the indices of abundance. Solving for *s*, the survival rate during the first 2 years of ocean residence of marked 3-freshwater Karluk sockeye, we obtain

$$s = \frac{1.494\ (0.10)}{0.657} = 0.227.$$

Adjusting for the effects of marking as above, the survival rate during the first 2 years of ocean residence of unmarked 3-freshwater Karluk sockeye is estimated to be 31.3%. Using 25.33 months as the duration of the first 2 years of ocean residence of 3-freshwater Karluk sockeye (table 2 of Fredin, MS, 1963), the average monthly instantaneous mortality rate during this period is estimated to be 0.046, approximately 50% greater than the average monthly instantaneous mortality rate during the third year of ocean life. The difference between the average monthly instantaneous rates indicates a temporal decrease in the oceanic mortality rate of salmon analogous to that simulated by Population Model 2 of Fredin (MS, 1963).

## DISCUSSION OF METHODS AND ESTIMATES

### MATURITY SCHEDULE METHOD

In deriving the equations for estimating an ocean mortality rate from data on maturity schedules and returns, the assumption is made that the survival rate during the last 2 months of ocean life is the same for 2- and 3-ocean fish of a given freshwater age group. Although this seems to be a reasonably acceptable assumption as it stands, its validity should be examined. In this regard, I have obtained some data from the Fisheries Research Institute, University of Washington, on the relative numbers of recoveries in Bristol Bay of 2- and 3-ocean sockeye that were tagged on the high seas 1–2 months prior to their return to the Bay in 1961 and 1963. The release and recovery data are as follows:

| Year | Area of tagging | No. of tagged fish released | | No. of tagged fish recovered | | Per cent recovered | |
|---|---|---|---|---|---|---|---|
| | | *2-ocean* | *3-ocean* | *2-ocean* | *3-ocean* | *2-ocean* | *3-ocean* |
| 1961 | 160° W to 180° | 1908 | 2071 | 358 | 320 | 18.8 | 15.5 |
| 1963 | 175° W to 180° | 151 | 139 | 11 | 8 | 7.3 | 5.8 |

Approximately one-half of the tagged sockeye released in 1961 were fish that had been captured in three purse seine sets. The other half was taken in 39 purse seine sets. Observations made during several years of tagging on the high seas, supported by data on recovery rates, indicate that when large numbers of sockeye are taken in a single purse seine set, tagged and released, the tagged fish suffer a greater mortality due to crowding and handling than when smaller numbers of fish are taken in a set.

Ignoring the releases and recoveries of the large number of tagged sockeye that were taken in three purse seine sets in 1961, the percentages recovered in Bristol Bay are as follows:

$$\text{2-ocean: } 227/992 = 22.9\%$$
$$\text{3-ocean: } 270/1090 = 24.8\%.$$

Judging from the foregoing data on releases and recoveries of tagged 2- and 3-ocean sockeye, the survival rate during the last 2 months of ocean life appears to be about the same for 2- and 3-ocean sockeye.

The Bristol Bay runs of 1.485 million 5.3 sockeye in 1958 and 0.787 million 6.3 sockeye in 1959 probably do not represent the total returns of these two age groups, since the Japanese gill net fishery took thousands of 5.3 and 6.3 sockeye in 1958 and 1959, respectively, in high seas areas where Bristol Bay sockeye occur. Table III shows the estimated catches of 5.3 and 6.3 sockeye by the Japanese gill net fishery to have been 0.076 and 0.184 million fish in 1958 and 1959, respectively, between 170° E and 175° E in May, between 175° E and 180° in May and June, and between 180° and 175° W in June and July. The numbers of 5.3 and 6.3 Bristol Bay sockeye in the high seas catches are not known. Based on the ratios of high seas catches to the numbers of 5.3 and 6.3 sockeye in the Bristol Bay runs ($0.076/1.485 = 0.05$, and $0.184/0.787 = 0.23$), it can be surmised that the Japanese fishery took a larger proportion of 6.3 Bristol Bay sockeye in 1959 than of 5.3 Bristol Bay sockeye in 1958. If this were the case, or if Bristol Bay sockeye accounted for the same proportions of the high seas catches of 5.3 and 6.3 fish in 1958 and 1959, respectively, the estimate of $s_{i3}$ (0.711) would be too low.

The magnitude and direction of error of the proportion of 2-ocean Bristol Bay sockeye assumed to mature in 1958 are not known. If more than 57.3% of the 2-ocean fish returned to Bristol Bay in 1958, the estimate of $s_{i3}$ would be low. If less than 57.3% of the 2-ocean fish returned to Bristol Bay in 1958, the estimate of $s_{i3}$ would be high. For example, if 62.3% of the 2-ocean Bristol Bay sockeye matured in 1958, the estimate of $s_{i3}$ would be 0.876, and the corresponding average monthly instantaneous ocean mortality rate would be about 0.011. If 52.3% of the 2-ocean Bristol Bay sockeye matured in 1958, the estimate of $s_{i3}$ would be 0.581, and the corresponding average monthly instantaneous ocean mortality rate would be about 0.045.

## OCEAN IMMATURES METHOD

In deriving the equation for estimating an ocean mortality rate from data on indices of abundance of immature 1- and 2-ocean sockeye at sea in 1 year and returns of 2- and 3-ocean fish in the following year, the assumption is made that the survival rate during the last 11 months of ocean life is the same for sockeye that mature as 2- and 3-ocean fish in a given year. Although this assumption seems also to be reasonably acceptable as it stands, its validity will be examined as additional data are compiled on the recoveries of mature 2- and 3-ocean sockeye that were tagged on the high seas as immature 1- and 2-ocean fish.

Concerning the usage of indices of abundance of immature 1- and 2-ocean sockeye south of Adak Island to represent the relative numbers of immature 1- and 2-ocean Bristol Bay sockeye at sea on August 1, a possible source of bias is the selectivity of purse seines for immature 1- or 2-ocean sockeye. In this regard, some unpublished data from joint fishing operations (involving purse seines, gill nets, and longlines) south of Adak Island in the summer of 1959 indicate that purse seines are selective for small (immature 1-ocean) sockeye (Fig. 2). If this is generally the case, the ratio of the average catch per seine set of immature 1-ocean sockeye to the average catch per seine set of immature 2-ocean sockeye would generally be greater than the ratio of immature 1- to 2-ocean sockeye in the high seas south of Adak Island, and also probably greater than the relative number of immature 1- and 2-ocean Bristol Bay sockeye at sea. In this event, the estimates of the proportion of Bristol Bay sockeye that mature as 2-ocean fish (equation 13), and $s_o$, the survival rate during the penultimate year of life of 3-ocean Bristol Bay sockeye (equation 12), would be low.

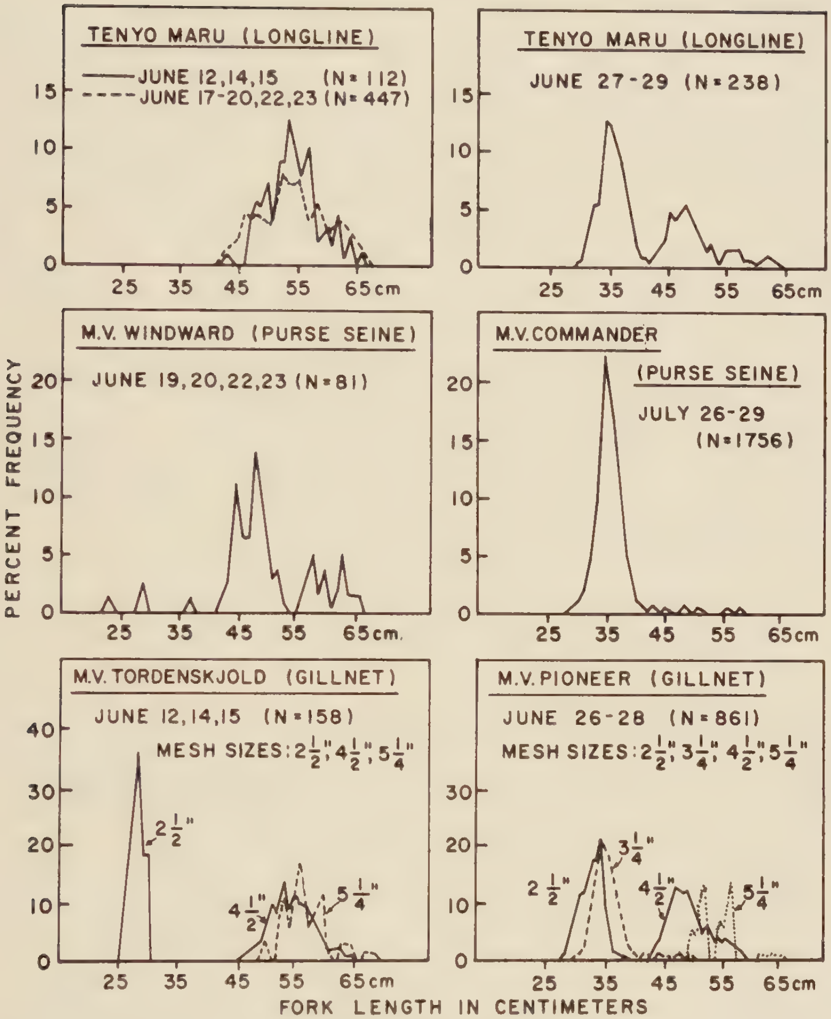

FIG. 2. Length frequency distributions of sockeye caught by longlines, purse seines and gill nets south of Adak Island in summer of 1959. (Unpublished data from Fisheries Agency of Japan, Fisheries Research Institute, University of Washington, and Bureau of Commercial Fisheries, compiled by R. H. Lander and R. R. French.)

The estimated catches of Bristol Bay sockeye by the high seas gill net fishery, hence the estimated total returns of 2- and 3-ocean Bristol Bay sockeye, cannot be considered to be precise. More detailed information on the age composition of the high seas catches would be useful for more accurate statistics on total returns.

## SMOLT INDICES METHOD

The principal assumptions carried in this method concern constant ocean survival conditions for successive smolt migrations during the first 2 years of ocean residence as well as during the third year of ocean life of 3-ocean fish. That such survival conditions do not generally prevail is shown by estimates of ocean mortality rates of Pacific salmon given by Ricker (1962), Parker (1962), and Fredin (MS, 1963). The variability in the regression of returns of 3-ocean Karluk sockeye per smolt index on returns of 2-ocean fish per smolt index also indicates that survival conditions during the first two and third years of ocean life are not the same for successive smolt migrations. (For example, the expected value for $R_{3x}/I_x$ from the equation, $R_{3x}/I_x = 1.494 - 0.657\ R_{2x}/I_x$, is 0.72 when $R_{2x}/I_x = 1.18$, as compared with the observed value of 0.49).

Although ocean survival conditions vary somewhat for different smolt migrations, and returns of 1- and 4-ocean fish were ignored in the analysis, the estimates of survival rates during the first two and third years of ocean life obtained by the smolt indices method are similar to those obtained under Population Model 2 of Fredin (table 9, MS, 1963) for 3-freshwater Karluk sockeye.

As far as smolt migrations are concerned, it might be no more difficult to estimate total numbers of seaward migrants than to determine the efficiency of a sampling device for obtaining indices of abundance of smolts.

## COMPARISON OF ESTIMATES

For 3-freshwater, 3-ocean (6.3) Bristol Bay sockeye that matured in 1959, the natural mortality rate during the year immediately preceding the last 2 months of ocean life is estimated to be 28.9%. This rate corresponds to an average monthly instantaneous mortality rate of 0.028.

The average annual ocean mortality rate during the penultimate year of life of 3-ocean Bristol Bay sockeye for the years, 1956–57 to 1960–61, is estimated to be 19.5%. This rate corresponds to an average monthly instantaneous mortality rate of 0.018.

From data on the returns of six groups of sockeye marked as smolts in the late 1920's and early 1930's, the natural mortality rate during the third year of ocean life of unmarked 3-freshwater Karluk fish is estimated to be 28.2%. This rate corresponds to an estimated average monthly instantaneous mortality rate of above 0.031.

Although the foregoing estimates pertain to different populations, age groups, and periods of time, and are based on different types of data and assumptions, they are similar to one another. The average of the three estimates of annual mortality rates is 25.5%, which is close to the estimate of 27% given by Parker (1962) for the annual ocean mortality rate of Pacific salmon.

## ACKNOWLEDGMENTS

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## REFERENCES

ALASKA DEPARTMENT OF FISH AND GAME. 1963. Forecast of Bristol Bay red salmon run in 1963. *International Leaflet* No. 23, 13 pp.

BARNABY, JOSEPH T. 1944. Fluctuations in abundance of red salmon *Oncorhynchus nerka* (Walbaum) of the Karluk River, Alaska. *U.S. Fish and Wildlife Serv.*, **50**: 237–295. (Fishery Bull. 39)

FREDIN, R. A. MS, 1963. Ocean mortality and maturity schedules of Karluk sockeye salmon and some comparisons of marine growth and mortality rates. 98 pp. Bureau of Commercial Fisheries, U. S. Fish and Wildlife Service, Seattle, Washington.

FUKUHARA, FRANCIS M., SUETO MURAI, JOHN L. LALANNE, AND ARPORNA SRIBHIBHADH. 1962. Continental origin of red salmon as determined from morphological characters. *Int. North Pacific Fisheries Comm., Bull.* No. 8, p. 15–109.

HARTT, A. C. 1962. Movement of salmon in the North Pacific Ocean and Bering Sea as determined from tagging. *Int. North Pacific Fisheries Comm., Bull.* No. 6, 157 pp.

INTERNATIONAL NORTH PACIFIC FISHERIES COMMISSION. 1956–1961. Annual reports for the years, 1956–1961.

1961. Proceedings of the eighth annual meeting, INPFC: Report of the Committee on Biology and Research, INPFC Doc. 491, 314 p.

1962. Proceedings of the ninth annual meeting, INPFC; INPFC Doc. 570, pp. 69–178.

1963a. Additional information on Alaska salmon, INPFC Doc. 602. (U. S. Section).

1963b. Proceedings of the tenth annual meeting, INPFC; INPFC Doc. 662, pp. 71–189.

MANZER, J. I., T. ISHIDA, A. E. PETERSON, AND M. G. HANAVAN. MS, 1963. Salmon of the North Pacific Ocean — Part V, Offshore distribution of salmon. INPFC Doc. 622.

MARGOLIS, LEO. 1963. Parasites as indicators of the geographical origin of sockeye salmon, *Oncorhynchus nerka* (Walbaum), occurring in the North Pacific Ocean and adjacent seas. *Int. North Pacific Fisheries Comm., Bull.* No. 11, pp. 101–156.

MOSHER, KENNETH H. 1963. Racial analysis of red salmon by means of scales. *Int. North Pacific Fisheries Comm., Bull.* No. 11, pp. 31–56.

PARKER, R. R. 1962. Estimations of ocean mortality rates for Pacific salmon (*Oncorhynchus*). *J. Fish. Res. Bd. Canada*, **19**(4): 561–589.

1963. On the problem of maximum yield from North Pacific sockeye salmon stocks. *J. Fish. Res. Bd. Canada*, **20**(6): 1371–1396.

RICKER, W. E. 1962. Comparisons of ocean growth and mortality of sockeye salmon during their last two years. *J. Fish. Res. Bd. Canada*, **19**(4): 531–560.

# Dropout Rate for High Seas Gillnets Studied by US Fisheries Biologists

by
**Robert R. French**

Among the objectives of a recent research cruise of the Bureau of Commercial Fisheries *George B. Kelez* was one to initiate studies on gill net dropouts, or the waste of salmon killed in gill nets but not landed. This cruise was part of the Bureau's continuing research on high-seas salmon conducted under the program of the International North Pacific Fisheries Commission, and was undertaken in the late summer of 1964 primarily to study the distribution, relative abundance, and migration routes of immature salmon known to pass westward along the Aleutian Islands during the summer.

Loss of salmon from high seas gill nets has been reported to be substantial. No one knows what percentage of salmon, both maturing and immature, escaping from the nets may perish before reaching the fishery or the spawning streams. We recognize, of course, that not all fish escaping from gill nets are lost, as witness the return to the commercial fishery of a high proportion of salmon marked by gill nets. Wastage of salmon from dropouts that may result during an extensive high seas gill net fishery is incompatible with the United States views on full utilization of the resource.

Fishing operations for distribution and dropout studies took place in the western North Pacific Ocean during the period September 1 to October 12, 1964. Captain Trygve Mathisen was master of the *Kelez,* biologist-in-charge was Charles Hunter and scientific assistants were Robert Carlson and Wendell Peterson.

The initial research method adopted by Bureau scientists to estimate the magnitude of dropouts was to determine the difference in numbers of salmon caught in gill nets fished for a long period compared to the cumulative catch of salmon caught in a series of short sets fished at the same time and place. To accomplish this, gill nets were set, hauled, and reset at intervals throughout the night.

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Conventional nylon gill nets (50 fathoms long and 4 fathoms deep) were fished in individual units of 4 shackles with each unit connected by a 30-fathom line. Each unit of gear consisted of 2 shackles of 4½-inch and 2 shackles of 3¼-inch mesh, mesh sizes that would capture most sizes of salmon present. A security snap, on each gear unit, allowed for easy connection and disconnection of units. Lighted buoys and radio buoys were attached to the net string to insure finding the gear during hours of darkness.

The fishing routine during the night was as follows:

8 p.m. Set gear units #1 #2 #3 #4
11 p.m. Haul #1, remove salmon and reset #1
2 a.m. Haul #1 and #2, remove salmon and reset #2
5 a.m. Haul #2 and #3 remove salmon and reset #3
8 a.m. Haul #3 and the last unit #4

This particular fishing routine enabled us to make catch comparisons of the different 3-hour periods during the night (8-11 p.m.; 11 p.m.-2 a.m.; 2-5 a.m.; 5-8 a.m.). Also, we were able to compare the catches taken in nets fished continuously with the sum of catches in individual gear units. For example, unit #4 fished for 12 hours, from 8 p.m. to 8 a.m., and catches in these nets were compared to the cumulative catch of the four individual units hauled at the end of each 3-hour period.

Four of the special dropout study sets were attempted during the cruise, as time and weather allowed; two sets provided usable catch data for our purposes. Two sets were unusable because of a combination of weather and tidal-current fatcors affecting the net string and because of difficulty encountered in hauling the gear. The stormy weather normal for the area and season made the nightlong fishing scheme difficult and habardous. The two usable sets resulted in catches of 257 and 239 salmon, nearly all immature Sockeye and Chum salmon. These came from an area located approximately 160 miles south of Attu Island, where salmon were relatively abundant during late September and October.

Results of fishing gill nets at different time periods during the night in September and October show that most salmon were taken in the early evening between the hours of 8 and 11 p.m. Fewest fish were caught between the hours of 11 p.m. and 2 a.m., although in set number 2 the catch for the period 5-8 a.m. was similar to the catch between 11 p.m. and 2 a.m.

The fact that the greatest part of the salmon catch apparently is taken in evening hours may ditcate, to some extent, the Japanese high seas gill net fishing schedule. In the mothership operation, gill nets usually are set between 4 p.m. and 8 p.m. and the gear retrieved aboard the catcher boat starting between midnight and 1 a.m.

Comparison of catches in nets fished continuously versus the cumulative catch in individual gear units fished over the same time period revealed that:

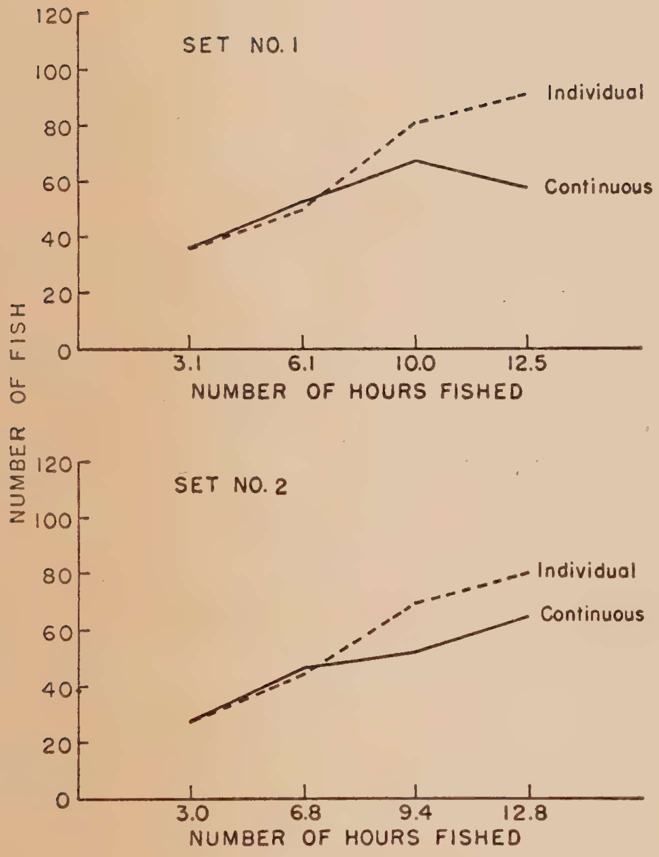
(1) After 6-7 hours of fishing there was little difference in the catch of nets fished for 6 hours and the cumulative catch in two gear units each fished for approximately three hours.

(2) After approximately 9-10 hours, less fish were taken in the nets fished nine hours compared to the number taken in three gear units each fished for three hours.

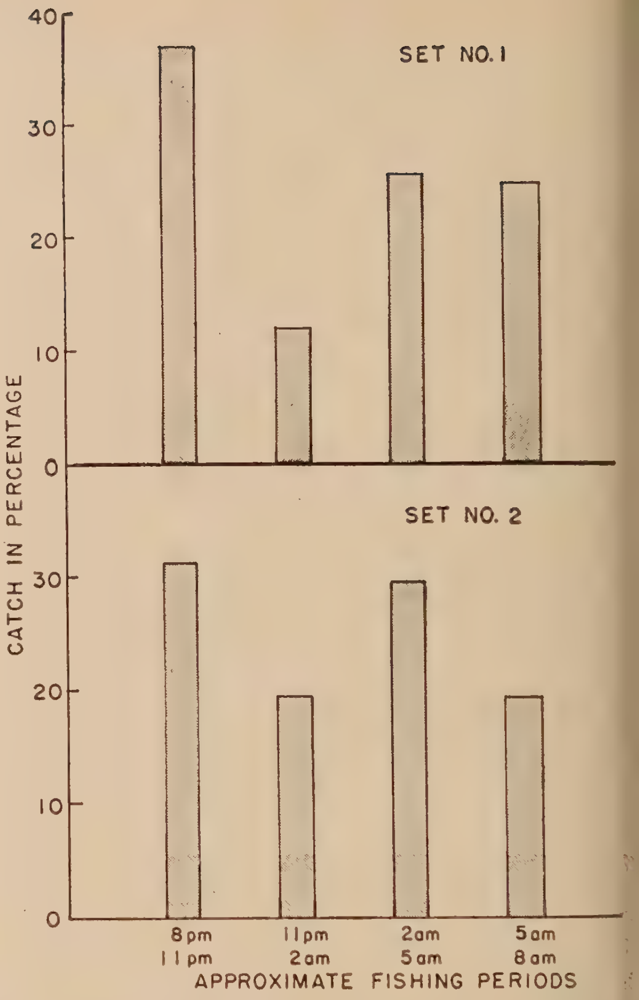
(3) After 12-13 hours less fish were taken in the gear units fished during the entire night than were taken in the four gear units each fished approximately three hours during the different time periods of the night.

These findings suggest a loss and possibly wastage of fish from gill nets fished over a long period of time.

The Bureau of Commercial Fisheries is continuing studies on loss of salmon from gill nets and will conduct research to determine rates of dropout and the ultimate fate of these salmon.



Comparison of the salmon catch in gill nets fished continuously with the cumulative catch in individual nets fished for short intervals during same time period.



Percentage of total gillnet catch taken in each of four 3-hour time periods.

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# Visceral Adhesions in High-Seas Salmon

Robert R. French

# Visceral Adhesions in High-Seas Salmon

Robert R. French

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## Abstract

Multiple mesenteric and peritoneal adhesions were recorded in sockeye and chum salmon obtained in 1957 through 1964 during the high seas sampling program. These adhesions were more prevalent among sockeye salmon examined during the 1963 summer research cruise in the North Pacific and winter cruise of 1964, with approximately 9 and 25 per cent respectively of the salmon afflicted. Adhesions were rare among chum salmon and not recorded among other salmon species. Of the sockeye with adhesions, most were fish which had spent 2 winters at sea, most were immature at time of capture, and the majority were males.

Visceral adhesions among salmonids reported in the literature are reported to be from infections of the nematode *Philonema* sp. The relationship between Pacific salmon and *Philonema* is unknown; also unknown is the ultimate effect on salmon of visceral adhesions.

## INTRODUCTION

Under the auspices of the International North Pacific Fisheries Commission, the Seattle Biological Laboratory is sampling salmon on the high seas in the Bering Sea and North Pacific Ocean to determine their distribution, abundance, and continent of origin. During examination of morphological features for racial determinations of several thousand salmon (*Oncorhynchus* sp.), biologists recorded instances of visceral organs tightly bound together and joined to the body wall by mesenteric and peritoneal adhesions. These adhesions occurred most often in sockeye salmon (*O. nerka*), rarely in chum salmon (*O. keta*), and were not observed in pink salmon (*O. gorbuscha*). Shipboard examination for sex and maturity stage of salmon caught during the 1963 summer research cruise indicated many instances of adhesions in sockeye salmon taken in the North Pacific Ocean south of Adak Island. This prompted a review of the frequency of this phenomenon in salmon for the years 1957 to 1964. This paper reports on the occurrence of visceral adhesions among salmon from high seas and inshore areas, biological data on these salmon, and gives possible reasons for the adhesions.

## ORIGINS AND EXAMINATION OF SALMON SAMPLES

During the period 1955 to 1962, samples of salmon were obtained from all principal fishery and escapement areas of North America, and from many places on the high seas, including the Japanese high seas fishery. These salmon were carefully dissected for morphological counts and measurements at the laboratory. The occurrence of visceral adhesions was incidentally noted and recorded as fused gonads. This was done because gonads from fish with adhesions were invariably damaged upon removal and therefore not suitable for weight comparisons.

In the period 1963 to 1964, pertinent biological data were collected aboard research vessels. Examples of visceral adhesions were usually not recorded; however, because of the high incidence noted by biologists aboard one vessel, all instances were recorded for several fishing sets during August and September 1963, and during January and February 1964.

## SALMON WITH VISCERAL ADHESIONS

### *Description of specimens*

Though not evident externally, visceral adhesions in salmon were easily recognized on internal examination. Visceral elements were tightly compacted and joined to the body wall with mesenteric and peritoneal adhesions. Because all organs were in a tightly compacted mass, determination of sex often necessitated tearing the adhesions joining the visceral mass to the body wall and removing the viscera. Other than being tightly compacted, the internal organs appeared normal, with alimentary canal, reproductive organs, and heart normally placed. Stomachs of salmon with visceral adhesions examined during the winter cruise of 1964 showed food items, including fish, similar to those found in normal fish. Total or regular food intake of fish with ad-

Table 1.—*Frequency of occurrence of sockeye and chum salmon with visceral adhesions, 1957 to 1964*

| Year and area | Sockeye | | | Chum | | |
|---|---|---|---|---|---|---|
| | Number examined | Number with visceral adhesions | Percentage | Number examined | Number with visceral adhesions | Percentage |
| 1957 | | | | | | |
| High seas | 4,684 | 0 | 0 | 6,448 | 0 | 0 |
| Inshore | 3,933 | 1 | 0.02 | 2,219 | 0 | 0 |
| 1958 | | | | | | |
| High seas | 4,612 | 8 | 0.17 | 6,202 | 0 | 0 |
| Inshore | 3,429 | 0 | 0 | 1,879 | 0 | 0 |
| 1959 | | | | | | |
| High seas | 6,524 | 27 | 0.41 | 6,654 | 6 | 0.09 |
| Inshore | 3,105 | 0 | 0 | 1,920 | 0 | 0 |
| 1960 | | | | | | |
| High seas | 9,373 | 174 | 1.86 | 5,046 | 1 | 0.02 |
| Inshore | 1,361 | 0 | 0 | 298 | 0 | 0 |
| 1961 | | | | | | |
| High seas | 5,669 | 30 | 0.53 | 4,306 | 0 | 0 |
| Inshore | 1,184 | 0 | 0 | 317 | 0 | 0 |
| 1962[1] | | | | | | |
| High seas | 12,301 | 261 | 2.12 | — | – | — |
| Inshore | 1,211 | 0 | 0 | — | – | — |
| 1963[2] | | | | | | |
| High seas | 1,164 | 105 | 9.02 | 1,232 | 0 | 0 |
| 1964[2] | | | | | | |
| High seas | 131 | 33 | 25.19 | 1 | 0 | 0 |

[1] Laboratory examination of chum salmon not completed at time of writing.

[2] Shipboard examinations only; laboratory examination of inshore samples were not made.

hesions compared to nonafflicted salmon is not known.

All specimens with adhesions observed during the summer of 1963 were immature with the characteristically small gonads of immature salmon; those fish taken in January and February, 1964, also had relatively small gonads, although serological test on females indicated the onset of maturity. Gonads of these specimens were in their normal position, lying below the kidneys, but tightly bound within peritoneal folds. One sockeye salmon showed eggs within the ovaries beginning to enlarge but still tightly bound within the peritoneum.

### *Occurrence of affected salmon*

The occurrence of sockeye and chum salmon with visceral adhesions from high seas and inshore samples is given in Table 1. The highest percentage was found during shipboard examination of sockeye salmon caught in 1963 and 1964. The 1963 samples were taken in August and September just south of Adak Island in the central Aleutians. In 1964 (January and February), they were taken in the North Pacific Ocean between latitudes 49° N and 50° N, and between longitudes 164° W and 174° W; two afflicted salmon were taken in the central Aleutians area of the Bering Sea. The incidence of adhesions, about 9 and 25 per cent for 1963 and 1964, was much greater than recorded in other years.

In only one instance was a fish with adhesions noted from inshore areas, all other afflicted fish were from high seas caught salmon. This particular female sockeye was reported from Fish Creek, Cook Inlet, Alaska, in 1957. Both ovaries of this specimen were reported fused and individual weights were not obtained; the ovaries, however, were removed and weighed together.

The question arises whether visceral adhesions were recognized and recorded as readily during laboratory examination of thawed specimens as during shipboard examination of freshly caught salmon, to permit a comparison of its occurrence over the years. In the laboratory, gonads of all salmon were removed for weighing; if adhesions were present, this could not be done because of mutilation and damage in removing the gonads. Specimens, therefore, were labeled as having fused gonads or fused viscera. In the opinion of laboratory personnel who had systematically dissected these fish over several years, visceral adhesions (called fused gonads) were always recorded as they were encountered among the salmon samples. Aboard research vessels in 1963 and 1964, visceral adhesions in salmon were easily recognized immediately upon eviscerating the fish and their occurrence was recorded. Therefore, the author feels that since visceral adhesions were recognized equally well in laboratory and shipboard examinations, the frequency of occurrence in the 1963 and 1964 samples represents a true increase.

Visceral adhesions in the observed specimens were noted mostly in sockeye salmon; they were rarely observed in chum salmon and never in the other salmon species. Chum salmon with visceral adhesions were taken on the high seas in 1959 and 1960 only. No adhesions were observed during the summer re-

TABLE 2.—*Sex and age composition of sockeye salmon with visceral adhesions*

| Year | Number with visceral adhesions | Sex composition[1] | | Age composition[1] | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | 1-winter | | | 2-winter | | | | 3-winter | | |
| | | Male | Female | $3_2$ | $4_3$ | $5_4$ | $3_1$ | $4_2$ | $5_3$ | $6_4$ | $5_2$ | $6_3$ | $7_4$ |
| 1957 | 1 | | 1 | | | | | | | | | | |
| 1958 | 8 | 3 | 5 | | 1 | | | 2 | 3 | | | 2 | |
| Per cent | | 37.5 | 62.5 | | 12.5 | | | 25.0 | 37.5 | | | 25.0 | |
| Per cent by winter age | | | | | 12.5 | | | 62.5 | | | | 25.0 | |
| 1959 | 27 | 19 | 3 | 5 | 2 | | | 9 | 5 | 3 | | | |
| Per cent | | 86.4 | 13.6 | 20.0 | 8.0 | | | 36.0 | 20.0 | 12.0 | | | |
| Per cent by winter age | | | | 32.0 | | | | 68.0 | | | | | |
| 1960 | 174 | 159 | 14 | 21 | 27 | | 1 | 79 | 23 | 6 | 4 | 1 | |
| Per cent | | 91.9 | 8.1 | 13.0 | 16.7 | | 0.6 | 48.8 | 14.2 | 3.7 | 2.5 | 0.6 | |
| Per cent by winter age | | | | 31.5 | | | | 65.5 | | | 3.0 | | |
| 1961 | 30 | 26 | 4 | | 4 | | | 8 | 14 | 1 | 1 | 1 | |
| Per cent | | 86.7 | 13.3 | | 13.8 | | | 27.6 | 48.3 | 3.4 | 3.4 | 3.4 | |
| Per cent by winter age | | | | 13.8 | | | | 79.3 | | | 6.9 | | |
| 1962 | 261 | 202 | 55 | 27 | 38 | 3 | | 60 | 81 | 13 | 3 | 10 | 1 |
| Per cent | | 78.6 | 21.4 | 11.4 | 16.1 | 1.3 | | 25.4 | 34.3 | 5.5 | 1.3 | 4.2 | 0.4 |
| Per cent by winter age | | | | 31.0 | | | | 63.5 | | | 5.6 | | |
| 1963 | 105 | 64 | 41 | 41 | 30 | 2 | | 15 | 4 | 1 | | 1 | |
| Per cent | | 61.0 | 39.0 | 43.6 | 31.9 | 2.1 | | 16.0 | 4.3 | 1.1 | | 1.1 | |
| Per cent by winter age | | | | 78.8 | | | | 20.2 | | | | 1.0 | |
| 1964 | 33 | 23 | 10 | | | | | 9 | 12 | | 4 | 3 | 1 |
| Per cent | | 69.7 | 30.3 | | | | | 27.3 | 36.4 | | 12.1 | 9.1 | 3.0 |
| Per cent by winter age | | | | 6.1 | | | | 69.7 | | | | 24.2 | |
| Total | 639 | 496 | 133 | 94 | 102 | 5 | 1 | 182 | 142 | 24 | 12 | 18 | 2 |
| Per cent | | 77.6 | 22.4 | 16.2 | 17.5 | 0.9 | 0.2 | 31.3 | 24.4 | 4.1 | 2.1 | 3.1 | 0.3 |
| Per cent by winter age | | | | 36.8 | | | | 58.0 | | | | 5.2 | |

[1] Fish lacking sex and age data are not included.

search cruise of 1963 when hundreds of chum salmon were examined. Between 1955 and 1962, over 25,000 pink salmon were examined in the laboratory with no observed visceral adhesions. Neither were adhesions observed in approximately 1,000 coho salmon (*O. kisutch*) examined during the 1963 summer cruise. Adhesions have not been noted among the relative few chinook salmon (*O. tshawytscha*) examined during recent research cruises.

### *Biological data*

Sex and age composition and maturity data of sockeye salmon with visceral adhesions are listed in Tables 2 and 3. Sockeye with adhesions that had spent 2 winters in the sea dominated all samples, except in 1963, when 1-winter-at-sea sockeye dominated. Within the winter age groups of afflicted salmon, there was no pronounced trend toward dominance of either age $3_2$ or age $4_3$ among 1-winter sockeye[1]; among the 2-winter fish dominance varied between age $4_2$ and age $5_3$ over the years. Only a few specimens were represented among the 3-winter group. Most of the sockeye with adhesions were males.

Maturity data (Table 3) show that most afflicted sockeye were immature fish. Gonad weights were used to designate stage of maturity of high-seas summer samples according to the method described by Ishida, Takagi, and Arita (1961). Of the 11 maturing sockeye with visceral adhesions, 10 were males; seven were 6-year-old fish, two were 5-year-old, and one a 4-year fish. For the 1964 winter cruise samples, serological methods on female sockeye (Ridgway, Klontz, and Matsumoto, 1962) were used to determine maturity stage of 36 females. Among eight fish with visceral adhesions, seven were maturing and one was judged immature.

All chum salmon with visceral adhesions (Table 1) were males. Age data were available for three fish; two were 2-year fish and one was a 3-year-old fish. No maturity data were obtained from these fish.

### *Possible causes of adhesions*

Several authors have associated visceral adhesions among salmonids with infestation by parasites. The parasite reported responsible for multiple visceral and peritoneal adhesions is the nematode *Philonema* sp.

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[1] Age designations are those of the Gilbert and Rich (1927) system of recording ages; the large type Arabic figure indicates total age when caught and the subscript the year of life in which it migrated from fresh water.

Kuitunen-Ekbaum (1933) first described the genus *Philonema*, and the new species *P. oncorhynchi*, from specimens taken in sockeye salmon caught in English Bay, British Columbia, Canada. She concluded that since examination showed that no larvae or mature stages of the worm had migrated into the fish muscles, the parasite may be considered practically harmless and the commercial value of sockeye not diminished by the infection. No mention was made of mesenteric or peritoneal adhesions.

Simon and Simon (1936) described a new species, *Philonema agubernaculum*, found in *Prosopium williamsoni*, *Salvelinus fontinalis*, and *Salmo shasta* (now considered *S. gairdneri*) in waters of the Wyoming National Forest, and noted that pathological changes occurred in the gonads of infected fish. Richardson (1937) named *Philonema salvelini* from *Salvelinus fontinalis* in Lake Edwards (Quebec) and stated that the presence of the nematode results in the formation of multiple mesenteric and peritoneal adhesions which bind the viscera into a compact mass. A case of an "egg-bound" female trout was recorded.

Meyer (1954, 1958) notes that the salmonid nematode, *Philonema agubernaculum*, has a very serious effect upon its host, the landlocked (Atlantic) salmon (*Salmo salar*) and brook trout (*Salvelinus fontinalis*). This parasite causes adhesions of the viscera, and in some cases, he states, "The organs are so strongly adhered together that neither normal spawning nor stripping is possible, in which case the female host is actually egg-bound."

Neiland[2] found that *Philonema* sp. "is endemic in the rainbow trout of the Tebay Lake system, Wrangell Mountains" in Alaska. He noted that the potential pathogenicity of *Philonema* had been reported elsewhere but found no marked inhibitions of spawning or gonad activity for Tebay Lake rainbows infected with *Philonema* sp. However, he reports, since philonemiasis is most common in the mature segment of the population it could easily depress reproduction without being highly pathogenic.

TABLE 3.—*Maturity data of sockeye salmon with visceral adhesions*

| Year | No. with visceral adhesions[1] | No. mature | No. immature | Per cent immature |
|---|---|---|---|---|
| 1957 | 1 | 1 | 0 | 0 |
| 1958 | 4 | 1 | 3 | 75 |
| 1959 | 16 | 0 | 16 | 100 |
| 1960 | 147 | 4 | 143 | 97.3 |
| 1961 | 28 | 2 | 26 | 92.9 |
| 1962 | 129 | 0 | 129 | 100 |
| 1963 | 105 | 3 | 102 | 97.1 |
| Total | 430 | 11 | 419 | 97.4 |

[1] Includes only samples for which maturity data are available.

The true relationship between the parasite *Philonema* sp. and visceral adhesions among sockeye and chum salmon is unknown. Apparently all salmon with *Philonema* do not develop adhesions. Canadian scientists (INPFC, 1956, 1957; Margolis, 1963) report the wide distribution of *Philonema oncorhynchi* in sockeye salmon. For example, 76 of 77 different samples of sockeye examined in 1957 from the coast of North America and the high seas showed the presence of the parasite in varying intensities of infection. No mention of visceral adhesions was made; however, many of the samples examined were of the visceral mass after it had been removed from the body cavity of the fish. Margolis states he has seen *Philonema oncorhynchi* in prespawning salmon with no evidence of visceral adhesions.[2]

Several of the sockeye salmon with adhesions taken in the North Pacific Ocean south of Adak Island during the summer of 1963 were returned to Seattle and examined for *P. oncorhynchi*. All fish contained the parasite in the body cavity in varying degrees of intensity. No examinations were made of nonfused salmon from this cruise.

## DISCUSSION

The biological significance of sockeye or chum salmon with visceral adhesions during their marine life phase is difficult to ascertain. In order for salmon with multiple adhesions, as observed among high-seas samples, to eventually spawn, they must undergo some physiological change. The gonads usually are so tightly bound within the peritoneum that normal development appears impossible. It has been suggested by colleagues that, as the salmon grows and develops and the maturation process commences, the adhesions disappear. We do not know if this occurs. If it does, characteristics of the adhesions must disappear to the extent that they are virtually unrecognizable among mature fish. For example, I have not observed visceral adhesions while dissecting and sexing many thousands of mature sockeye salmon in Alaskan canneries or from the spawning grounds.

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[2] Personal communication.

If these afflicted salmon die before reaching maturity, and we have no evidence that they do, adhesions could be a severe natural mortality factor some years. Such early deaths would surely affect tag returns if substantial numbers of afflicted salmon were tagged during high seas tagging programs.

The high incidence of visceral adhesions noted among sockeye salmon in 1963 and 1964 merits further study of the phenomenon. Research is necessary to define the relationship between adhesions and parasites, if parasites are responsible. Certainly the ultimate effect of visceral adhesions in salmon should be determined.

## ACKNOWLEDGMENTS

I would like to acknowledge the assistance of Mr. Joseph Uzmann, Western Fish Disease Laboratory, Bureau of Sport Fisheries and Wildlife, for recognizing visceral adhesions and their possible causes, and for aid in identifying *Philonema oncorhynchi.*

## LITERATURE CITED

GILBERT, C. H., AND W. H. RICH. 1927. Second experiment in tagging salmon in the Alaska Peninsula fisheries reservation, summer of 1923. Bull. of the U.S. Bureau of Fisheries. 42: 27–75.

ISHIDA, R., K. TAKAGI, AND S. ARITA. 1961. Criteria for the differentiation of mature and immature forms of chum and sockeye salmon in northern seas. Int. North Pacific Fish. Comm., Vancouver, Canada. Bull. 5: 27–47.

INTERNATIONAL NORTH PACIFIC FISHERIES COMMISSION. 1956. Annual Report for 1955. Vancouver, Canada. 67 p.

———. 1957. Annual Report for 1956. Vancouver, Canada. 88 p.

KUITUNEN-EKBAUM, E. 1933. *Philonema oncorhynchi* gen. n. et sp. Contrib. Canadian Biol. and Fish. 8(4): 73–75.

MARGOLIS, LEO. 1963. Parasites as indicators of the geographical origin of sockeye salmon, *Oncorhynchus nerka* (Walbaum), occurring in the North Pacific Ocean and adjacent seas. Int. North Pacific Fish. Comm., Vancouver, Canada. Bull. 11: 101–156.

MEYER, M. C. 1954. The larger animal parasites of the fresh-water fishes of Maine. Maine Dept. Inland Fish. and Game. Bull. 1: 92 p.

———. 1958. Studies on *Philonema agubernaculum,* a dracunculoid nematode infecting salmonids. J. Parasit. 44(4, Sec. 2) 42.

RICHARDSON, L. R. 1937. Observations on the parasites of the speckled trout in Lake Edward, Quebec. Trans. Amer. Fish. Soc. 67: 343–356.

RIDGWAY, G. J., G. W. KLONTZ, AND C. MATSUMOTO. 1962. Intraspecific differences in serum antigens of red salmon demonstrated by immunochemical methods. Int. North Pacific Fish. Comm., Vancouver, Canada. Bull. 8: 1–13.

SIMON, J. R., AND FELIX SIMON. 1936. *Philonema agubernaculum* sp. n. (*Dracunculidae*), a nematode from the body cavity of fishes. Parasitology 28(3): 440–442.

# SERIAL ATLAS
# OF
# THE MARINE ENVIRONMENT

## Folio 10

## Autumn Distribution of Groundfish Species
## In the Gulf of Maine and Adjacent Waters, 1955-1961

RAYMOND L. FRITZ
U. S. Bureau of Commercial Fisheries

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# AUTUMN DISTRIBUTION OF GROUNDFISH SPECIES
## IN THE GULF OF MAINE AND ADJACENT WATERS, 1955-1961

RAYMOND L. FRITZ
*U. S. Bureau of Commercial Fisheries*

This Folio summarizes and illustrates the autumn distribution twenty common groundfish species in the Gulf of Maine, on eorges Bank, and in adjacent waters, and describes these disibutions in relation to depth and bottom water temperature.

The data were collected by the Bureau of Commercial sheries Biological Laboratory, Woods Hole, Massachusetts, n cruises designed to estimate the strength of new year-classes haddock. The earliest that this could be done was in the tumn months, and all of the cruises accordingly took place this time. Cruises were conducted each year from 1955 rough 1961, with the exception of 1957. The schedule of uises is as follows:

| ries | Vessel | Cruise Number | Date | No. Stations |
|---|---|---|---|---|
| 1 | **Albatross III** | 65,66 | 7-28 Sept. 1955 | 138 |
| 2 | **Albatross III** | 81,82 | 2-21 Nov. 1956 | 94 |
| 3 | **Albatross III** | 118, 119, 120 | 22 Sept. -28 Oct. 1958 | 114 |
| 4 | **Delaware** | 59-12, 59-13 | 23 Sept. -27 Oct. 1959 | 147 |
| 5 | **Delaware** | 60-12 | 2-21 Nov. 1960 | 117 |
| 6 | **Delaware** | 61-19 | 25 Oct.-20 Nov. 1961 | 151 |
|  |  |  | Total | 761 |

The area covered by the cruises (Plate A) extends from ape May, New Jersey (39°12′N.), northward to the Bay of undy (44°12′N.), and eastward along the Continental Shelf Nova Scotia (64°30′W.). Depths ranged from 30 meters approximately 410 meters along the edge of the Continental helf.

The sampling patterns were changed from year to year in n attempt to improve the estimates of haddock abundance. s a consequence some areas were sampled much more inensively than others. The variation in sampling intensity is nown in Plate A.

### Collecting Technique

The *Albatross III* and *Delaware* are side trawlers, similar those used in the New England commercial trawl fishery. n the survey cruises the gear used for collecting the fish was standard No. 36 redfish trawl (Knake, 1956) lined with ½ inch stretched-mesh netting. Wooden rollers were used on e foot-rope in order to trawl over areas of rough bottom.

At each collecting station the trawl was towed for ½ hour t a vessel speed of approximately 3 knots. The direction f towing generally followed the depth contours. After the ow was completed, the net was opened and emptied on deck. he catch was then sorted by species, and each fish was counted nd measured.

On all cruises, water temperature was measured at the surace with a bucket thermometer and to 300 meters with a athythermograph (BT). A BT cast was made at each station nd, generally, at 10-mile intervals between stations.

### Reduction of Data

The species distribution charts, Plates 1-20, and Table 1, resent the average fall distribution of the species as computed rom the combined data for all cruises. Adjustments were not ade to the catch data based on time of day. In computing he average catch per ½ hour tow for contouring, it was ecessary to use a larger unit area for species of lesser abunance. For the more abundant species the unit area is 18 inutes; for the species of less abundance, 30 minutes. The atch per tow for the unit area used in contouring is the average catch per tow for all stations lying within that unit area occupied on any of the cruises. The size of the unit area is indicated in the legend for each species distribution chart, Plates 1-20.

The values for unit areas were plotted in the centers of the unit areas and the contour values interpolated between these centers, except in cases where the bathymetry required adjustments in order to avoid contouring a species outside its normal depth range as shown by the original station data.

For example, the argentine (*Argentina silus*, Plate 4) is seldom taken in depths less than 100 meters off the Northern Edge of Georges Bank. However, the 18-minute squares on the Northern Edge encompass depths from 60 to 200 meters. It was therefore necessary to adjust the abundance contour lines to correspond with the depth distribution of this species as indicated by the data from individual stations throughout that area.

The wide differences in catch per tow from one species to another made it necessary to adopt different scales of abundance for different species. For example, the catch per tow of redfish (*Sebastes marinus*, Plate 18) ranged from 1 to 1,000. In contrast, the catch per tow of longhorn sculpin (*Myoxocephalus octodecimspinosus*, Plate 19) ranged from 1 to 40.

A generalized chart of bottom types (Plate B) is included for those who wish to compare them with the distributional pattern of fishes. Since bottom types tend to be correlated with depth, it is difficult—without additional data—to assign either factor as the prime reason for the occurrence of fish. In most cases depth appears to be the controlling factor.

### Bottom Temperatures

The average bottom temperatures observed during the survey cruises are shown on Plate C. The mean bottom temperatures were calculated for each 20-minute square and isotherms drawn for each degree of water temperature.

A relatively strong temperature gradient divides the area surveyed into a colder northern, or boreal region and a warmer southern, or temperate region. This temperature gradient usually runs along the Northern Edge of Georges Bank across the South Channel to Nantucket Shoals. North of this gradient, in the Gulf of Maine, bottom temperatures ranged from 5° C in the deeper water, to 9° C in the shallower water; south and west of the gradient temperatures varied from 10° C at the edge of the Continental Shelf to 14° C and 20° C in the inshore areas.

A pocket of cold water (less than 10° C) typically occurs on the Continental Shelf between Cape Cod and Cape Hatteras. This cold water pocket forms early in the spring and remains until winter (Bigelow, 1922).

### Discussion

It has long been recognized by marine biologists that Cape Cod represents the southern boundary of most boreal species. Similarly, it is also the northern boundary of many temperate species. Some groundfish species are clearly confined to each region, but others, at times, extend their range seasonally into the adjoining region. For example, cod (*Gadus morhua*, Plate 6), a typical boreal species, may migrate as far south as Virginia during the winter months when temperature conditions are suitable. Butterfish (*Poronotus triacanthus*, Plate 16), a typical Middle Atlantic or temperate region species, migrate into the Gulf of Maine during the summer months. Other groundfish species, including the hakes, are found both north and south of Cape Cod throughout the year.

Argentine, redfish, sea herring (*Clupea harengus*, Plate 3), and haddock (*Melanogrammus aeglefinus*, Plate 7), are representative boreal species. They occur over a wide range of depths and temperatures, but are most abundant in the colder waters. Argentines were taken in large quantities between Georges Bank and Browns Bank and were occasionally caught along the slope of the Continental Shelf south of Georges Bank. They generally were found in depths greater than 120 meters and in temperatures less than 8° C. Redfish were commonly caught in the deep waters of the Gulf of Maine and almost never west of Cape Cod. This species generally was found in depths greater than 150 meters and in water temperatures of approximately 7° C. Large quantities of sea herring were taken along the western side of Georges Bank, in the Channel between Cape Cod and Georges Bank, and along the Northern Edge of Georges Bank. They were most abundant at depths of 170 meters and in temperatures between 6° and 9° C. Haddock were abundant in the Great South Channel along the Northern Edge of Georges Bank, and on Browns Bank from 50 to 130 meters and usually in water less than 11° C.

Scup (*Stenotomus versicolor*, Plate 17), butterfish, fourspot flounder (*Paralichthys oblongus*, Plate 13), and yellowtail flounder (*Limanda ferruginea*, Plate 14), are typical temperate region species. They generally occur in shallower and warmer waters during the autumn months. The largest quantity of scup in the autumn survey cruises was caught in depths from 30 to 70 meters where the temperature ranged from 13° to 16° C. Butterfish were abundant in depths between 50 and 90 meters and in water temperatures of about 11° C. Yellowtail flounder and fourspot flounder were most abundant on Georges Bank and south of Cape Cod in depths between 50 and 90 meters, and water temperatures between 9° and 14° C.

Species that range widely over both regions include silver hake (*Merluccius bilinearis*, Plate 5), squirrel hake (*Urophycis chuss*, Plate 10), and spiny dogfish (*Squalus acanthias*, Plate 1). Of all the species discussed in this Folio, silver hake was the most widely distributed and was abundant in shoal as well as deep water. Large catches usually were made off Cape Cod and along the periphery of Georges Bank. The species was taken in depths from 70 to 210 meters, and in waters where temperatures ranged from 6° to 12° C. Squirrel hake was also taken throughout the study area, and was most abundant in 90 meters and in waters which ranged from 8° to 10° C. Spiny dogfish were caught in large quantities north of Cape Cod, off the Northern Edge of Georges Bank, and on the Continental Shelf south of Georges Bank. Incidental catches of this species were taken throughout the study area. The species was taken between 30 and 50 meters in waters generally from 8° to 12° C.

Summaries of the depth and temperature relationships for six species of groundfish are presented in Figure 1. Silver hake, squirrel hake, and haddock were caught over a wide range of depths and temperatures. In contrast, yellowtail flounder were found in a wide range of temperatures but were confined to the shoal water. Redfish and white hake (*Urophycis tenuis*, Plate 9) were taken in the deeper waters within which there was a small range in temperature.

The availability of a species to fishing gear varies with the activity of the species, and this in turn may vary with the time of day resulting in considerable variation in apparent abundance throughout a 24-hour cycle. Figure 2 presents such changes for six species. Spiny dogfish, pollock, butterfish, and redfish were caught mainly during the daylight hours. Catches of longhorn sculpin and scup decreased during the daytime and increased at night. Other species do not show any change in apparent abundance during the daily cycle.

### References

**Bigelow, H. B.** (1922)
*Bull. Mus. Comp. Zool.*, 65 : 87-188.
Exploration of the coastal water off the northeastern United States in 1916 by the U.S. Fisheries schooner *Grampus*.

**Knake, B. O.** (1956)
*Fishery Leaflet, U.S. Fish Wildl. Serv.*, (437) : 29 p.
Assembly methods for otter trawl nets.

**Uchupi, E.** (1963)
*U.S. Geol. Survey, Prof. Paper* 475C, Art. 94 : C132-C137.
Sediments on the continental margin off eastern United States.

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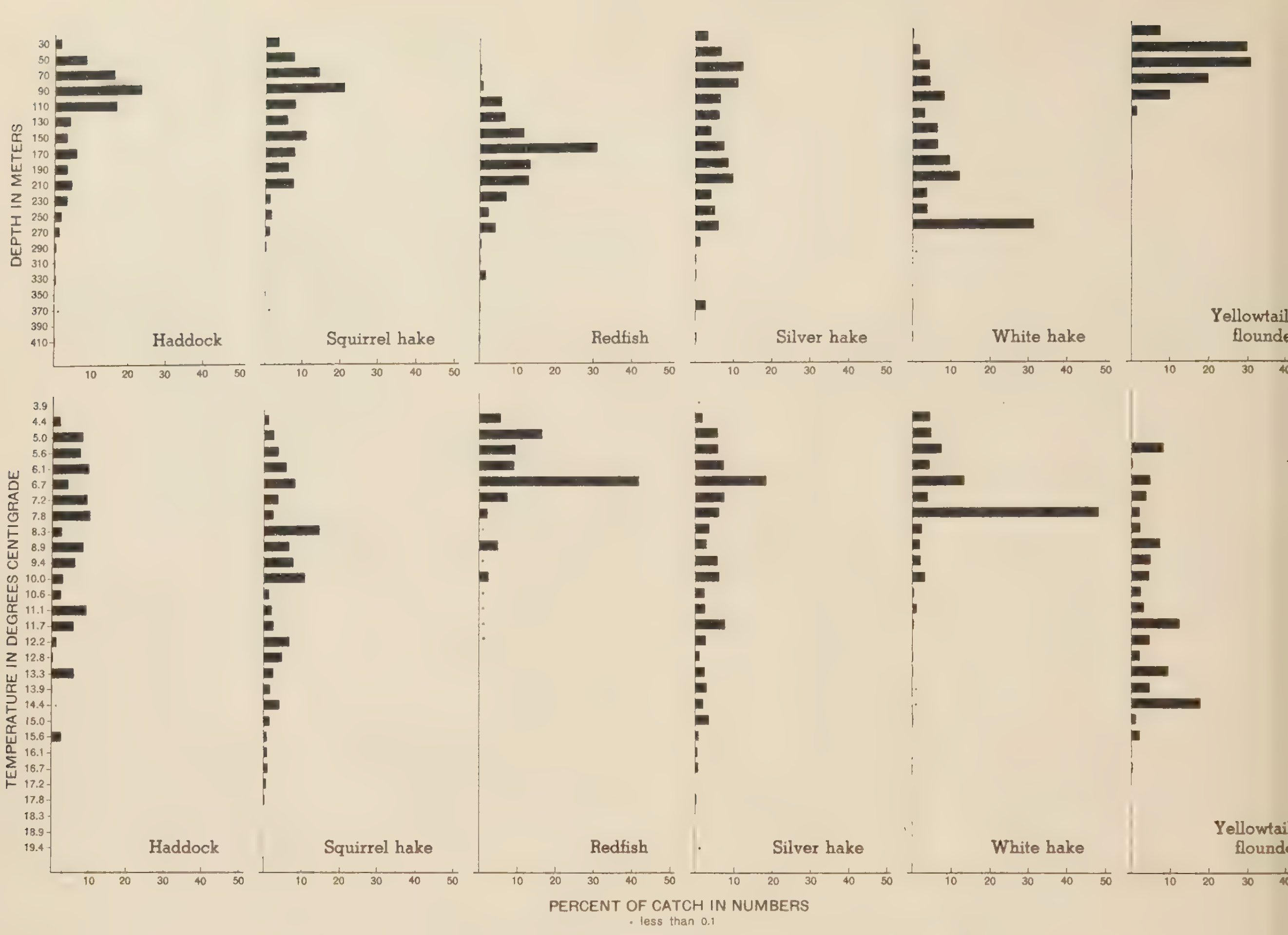


**Figure 1.** *(Above)* Relative abundance, related to depth, of six groundfish species. *(Below)* Relative abundance of the six species, related to bottom temperature.

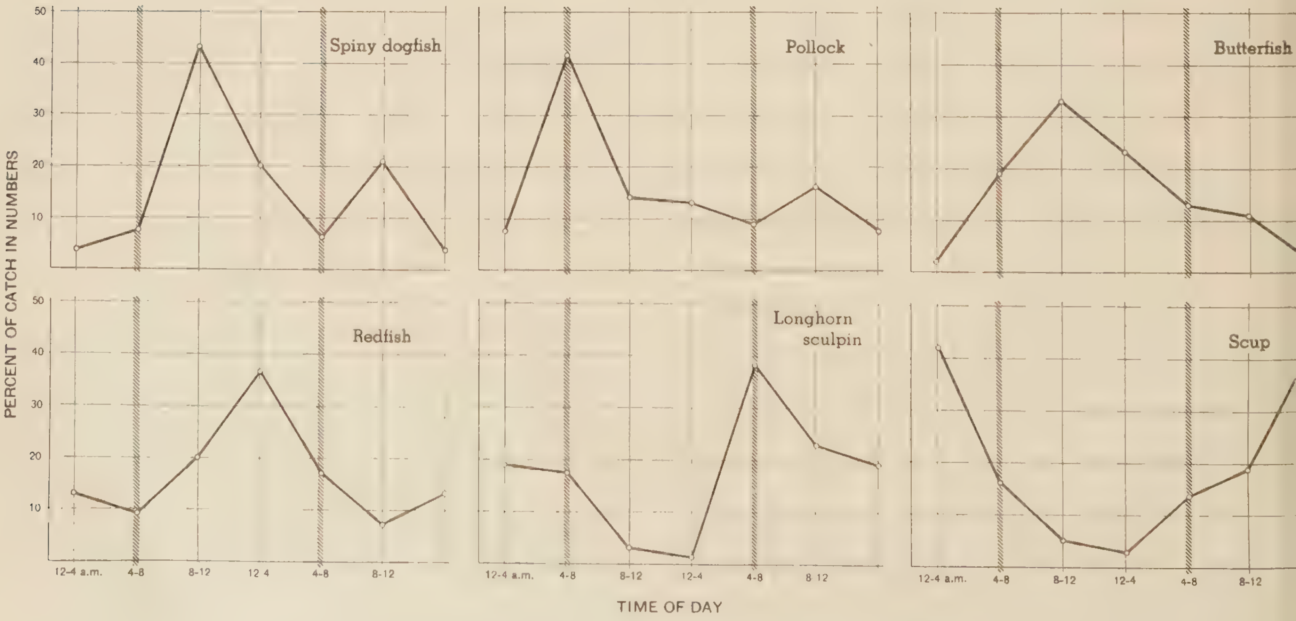


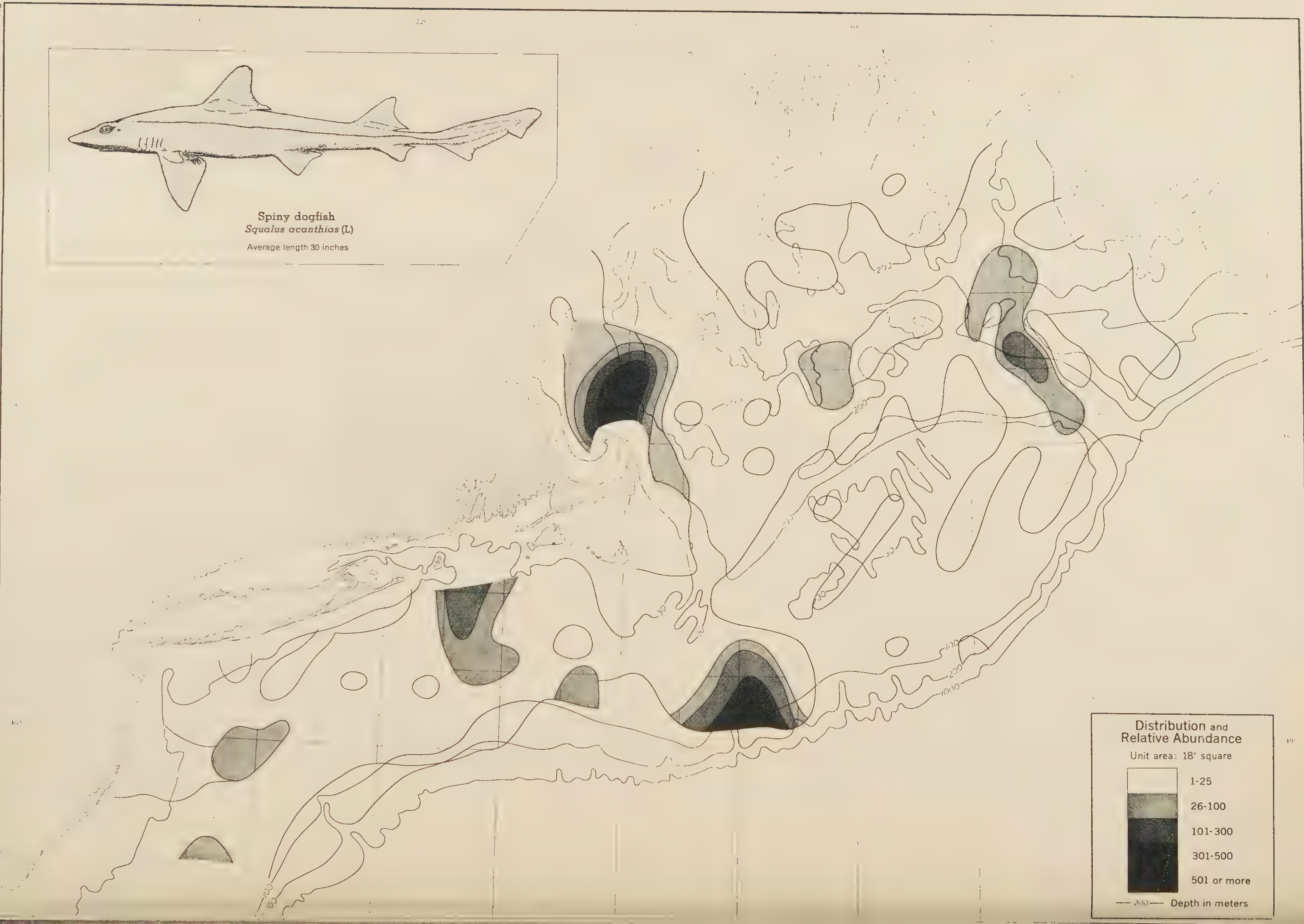
Figure 2. Variation in catch, by time of day, for six groundfish species, as determined by autumn survey cruise data. The dashed lines indicate dawn and dusk.

Table 1. Schedule of the twenty species presented in this Folio, with general distribution, range of depths, and range of bottom temperatures as observed on the autumn survey cruises

| PLATE NO. | SPECIES | OCCURRENCE | DEPTH (M) | BOTTOM TEMP. (C°) |
|---|---|---|---|---|
| 1 | Spiny dogfish<br>*Squalus acanthias* (L) | Throughout the area—Nova Scotia to Cape May, New Jersey. Abundant north of Cape Cod, off Nova Scotia, and southern New England. | 30-330 | 3.9 - 16.7 |
| 2 | Thorny skate<br>*Raja radiata* (Donovan) | North of 41°00′ Latitude. Light concentration on Georges Bank. | 50-410 | 3.9 - 16.7 |
| 3 | Sea herring<br>*Clupea harengus* (L) | North of 41°00′ Latitude. Abundant on western side of Georges Bank, north of Cape Cod, south of Nova Scotia, and east of Nantucket. | 30-370 | 4.4 - 15.0 |
| 4 | Argentine<br>*Argentina silus* (Ascanius) | In the Gulf of Maine and between Georges Bank and Browns Bank. | 50-410 | 5.6 - 13.9 |
| 5 | Silver hake<br>*Merluccius bilinearis* (Mitchell) | Throughout the area—Nova Scotia to New Jersey. Abundant off Cape Cod, western side of Georges Bank, southeastern part of Georges Bank, and south of Cape Cod. | 30-410 | 3.9 - 19.4 |
| 6 | Cod<br>*Gadus morhua* (L) | North of 41°00′ Latitude. Abundant off Nantucket, north of Cape Cod, and southeast of Nova Scotia. | 30-310 | 4.4 - 15.6 |
| 7 | Haddock<br>*Melanogrammus aeglefinus* (L) | North of 41°00′ Latitude. Abundant on the Northern Edge of Georges Bank and on Browns Bank. | 30-410 | 3.9 - 15.6 |
| 8 | American pollock<br>*Pollachius virens* (L) | North of 41°00′ Latitude. Heavy concentrations near Nova Scotia. Moderate concentrations in the Gulf of Maine and on the western side of Nova Scotia. | 30-370 | 4.4 - 12.2 |
| 9 | White hake<br>*Urophycis tenuis* (Mitchill) | North of 41°00′ Latitude. Abundant along the northeastern edge of Georges Bank and in the Gulf of Maine. | 30-410 | 4.4 - 15.0 |
| 10 | Squirrel hake<br>*Urophycis chuss* (Walbaum) | Throughout the area—Nova Scotia to Cape May, New Jersey. Abundant south of Cape Cod. | 30-370 | 4.4 - 17.8 |
| 11 | Longfin hake<br>*Urophycis chesteri*<br>(Goode and Bean) | In the deep waters of the Gulf of Maine off the Northern Edge of Georges Bank. | 150-410 | 4.4 - 10.6 |
| 12 | American dab<br>*Hippoglossoides platessoides*<br>(Fabricius) | North of 41°00′ Latitude. Abundant along the inshore waters north of Cape Cod and southeast of Nova Scotia. | 30-330 | 3.9 - 16.7 |
| 13 | Fourspot flounder<br>*Paralichthys oblongus* (Mitchill) | South of 42°00′ Latitude. Abundant from the eastern side of Georges Bank southward to Hudson Canyon. | 30-130 | 6.7 - 19.4 |
| 14 | Yellowtail flounder<br>*Limanda ferruginea* (Storer) | Along the eastern side of Georges Bank southward to Hudson Canyon and north of Cape Cod. Abundant on Georges Bank, north of Cape Cod, and off southern New England. | 30-190 | 5.6 - 16.7 |
| 15 | Witch flounder<br>*Glyptocephalus cynoglossus* (L) | North of 41°00′ Latitude. Abundant off the coast of Massachusetts and Maine and southeast of Nova Scotia. | 70-410 | 3.9 - 16.1 |
| 16 | Butterfish<br>*Poronotus triacanthus* (Peck) | South of 41°00′ Latitude. Abundant south of Cape Cod to Hudson Canyon. | 30-270 | 4.4 - 20.6 |
| 17 | Scup<br>*Stenotomus versicolor* (Mitchill) | South of 41°00′ Latitude. Abundant south of Cape Cod. | 30-170 | 8.9 - 20.6 |
| 18 | Redfish<br>*Sebastes marinus* (L) | North of 41°00′ Latitude. Abundant in the deep waters of the Gulf of Maine and southeast of Nova Scotia. | 50-410 | 4.4 - 15.6 |
| 19 | Longhorn sculpin<br>*Myoxocephalus octodecimspinosus*<br>(Mitchill) | South of 42°00′ Latitude. Abundant on Georges Bank and southeast of Cape Cod. | 30-370 | 4.4 - 15.6 |
| 20 | American goosefish<br>*Lophius americanus*<br>(Cuvier and Valenciennes) | Throughout the area—Nova Scotia to Hudson Canyon. Abundant along the Northern Edge of Georges Bank. | 30-310 | 3.9 - 15.6 |

# SPINY DOGFISH

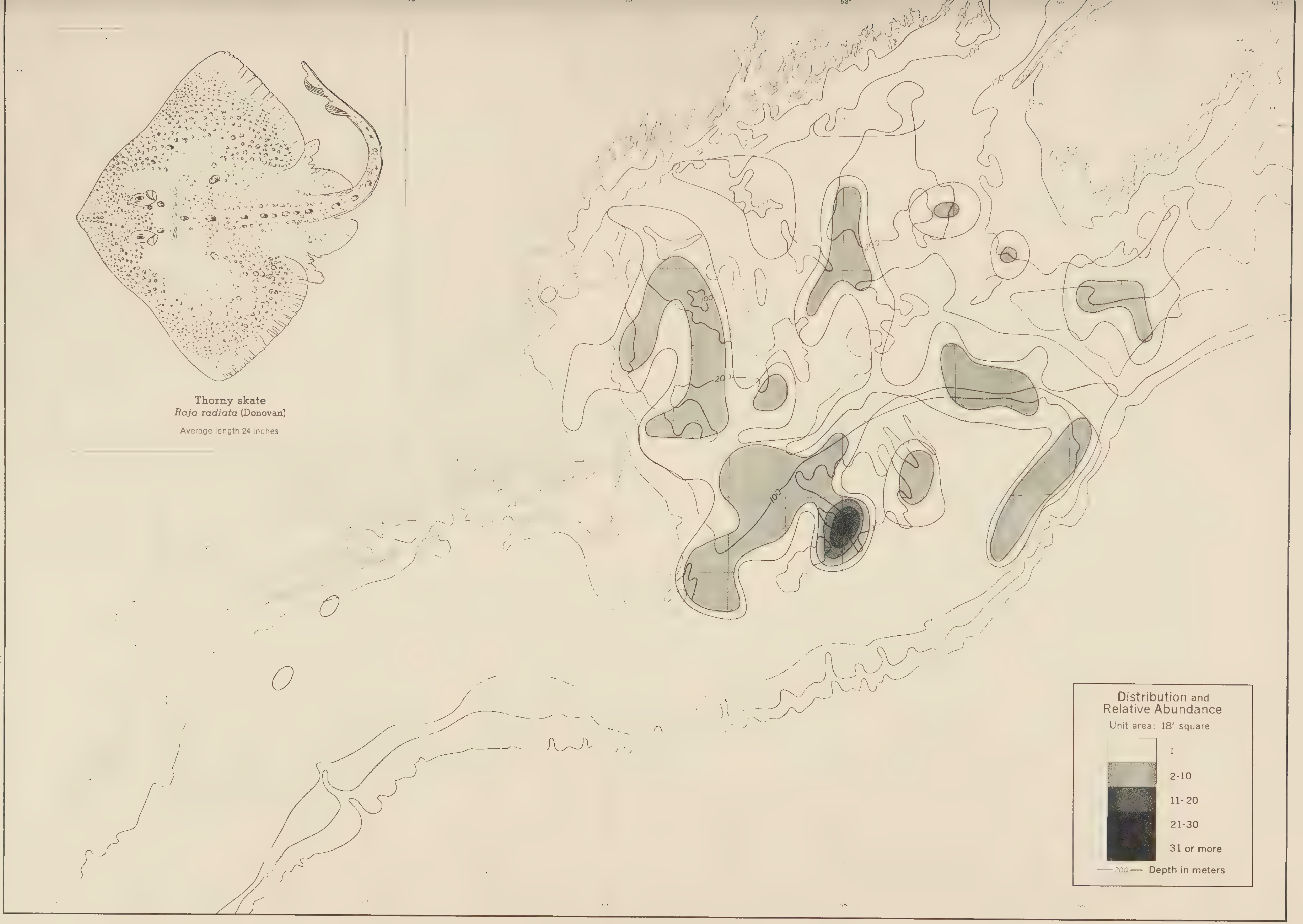
PLATE 1



Spiny dogfish
*Squalus acanthias* (L)
Average length 30 inches

Distribution and Relative Abundance
Unit area: 18' square
1-25
26-100
101-300
301-500
501 or more
200 Depth in meters
30
100
200
1000

*Oblique stereographic conformal projection for the North Atlantic, center 54°N. 38°W.*


Distribution and
Relative Abundance
Unit area: 18′ square
1
2-10
11-20
21-30
31 or more
200 Depth in meters
100
200
20
100

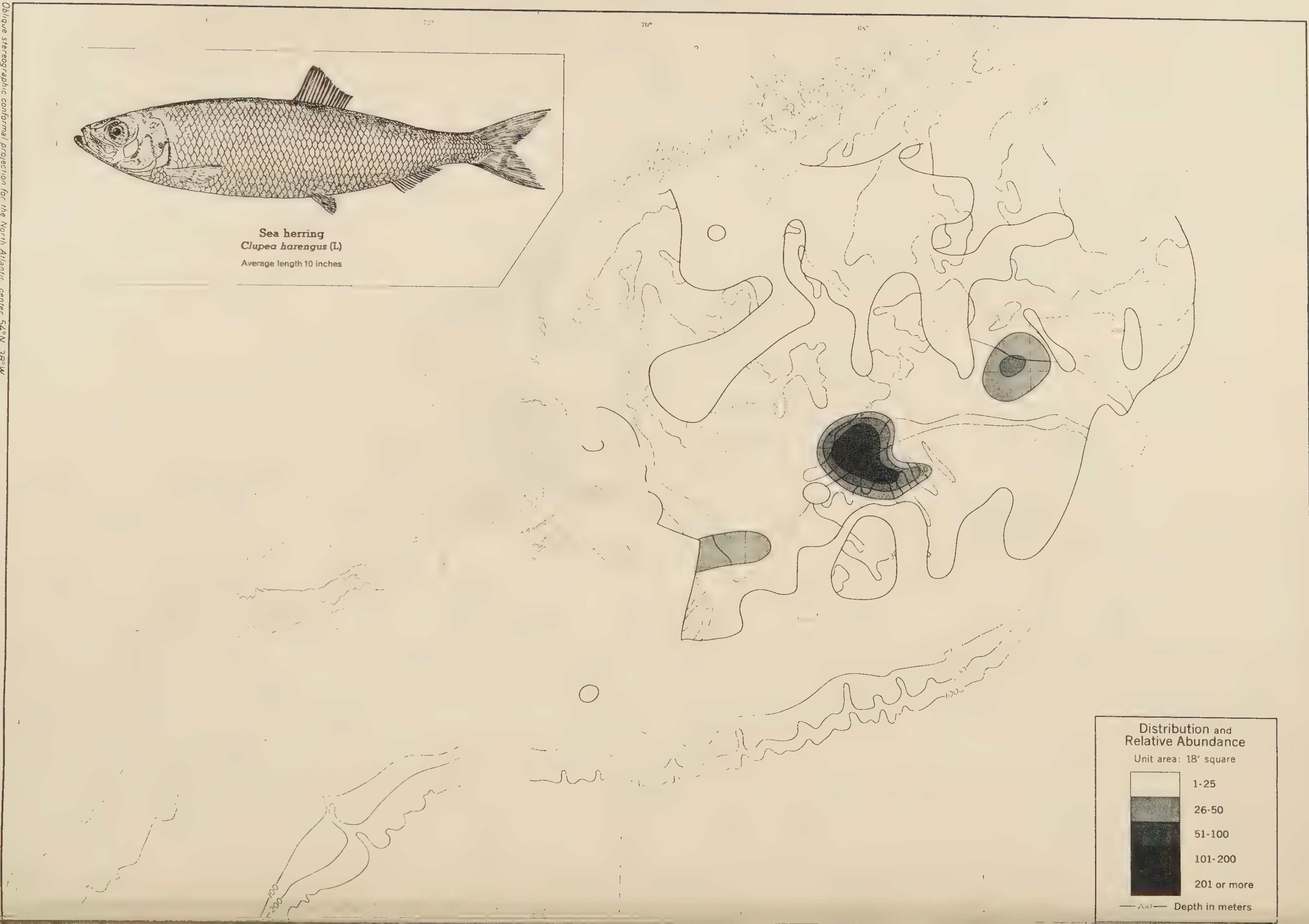
Thorny skate
*Raja radiata* (Donovan)
Average length 24 inches

NOMINAL SCALE 1:2,500,000

*Lithographed by Princeton Polychrome Press, Princeton, N.J.*

PLATE 3

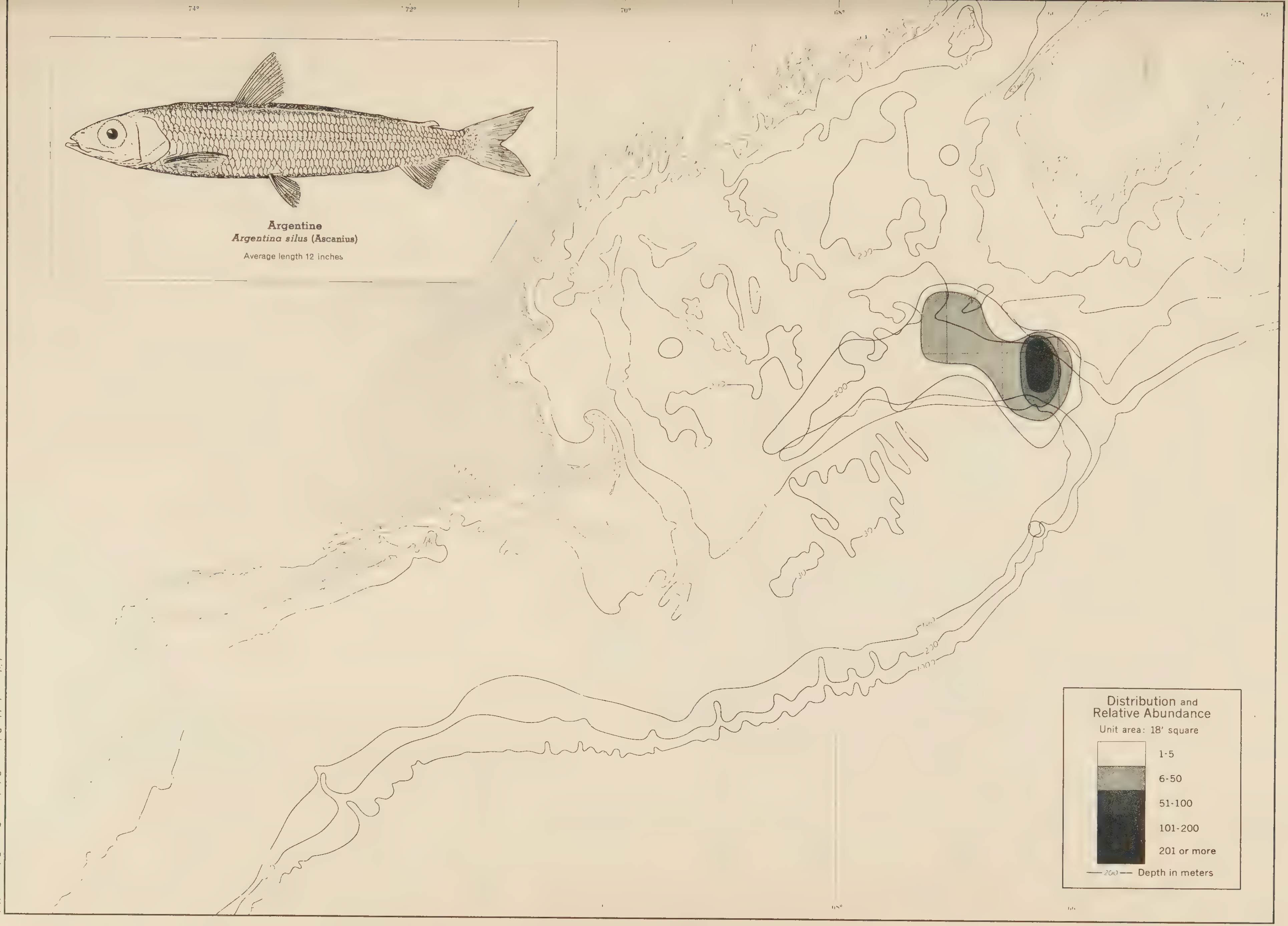
# SEA HERRING



70°
65°
100
200
Distribution and Relative Abundance
Unit area: 18' square
1-25
26-50
51-100
101-200
201 or more
200 Depth in meters

**Sea herring**
*Clupea harengus* (L.)
Average length 10 inches

*Oblique stereographic conformal projection for the North Atlantic, center 54°N. 38°W.*

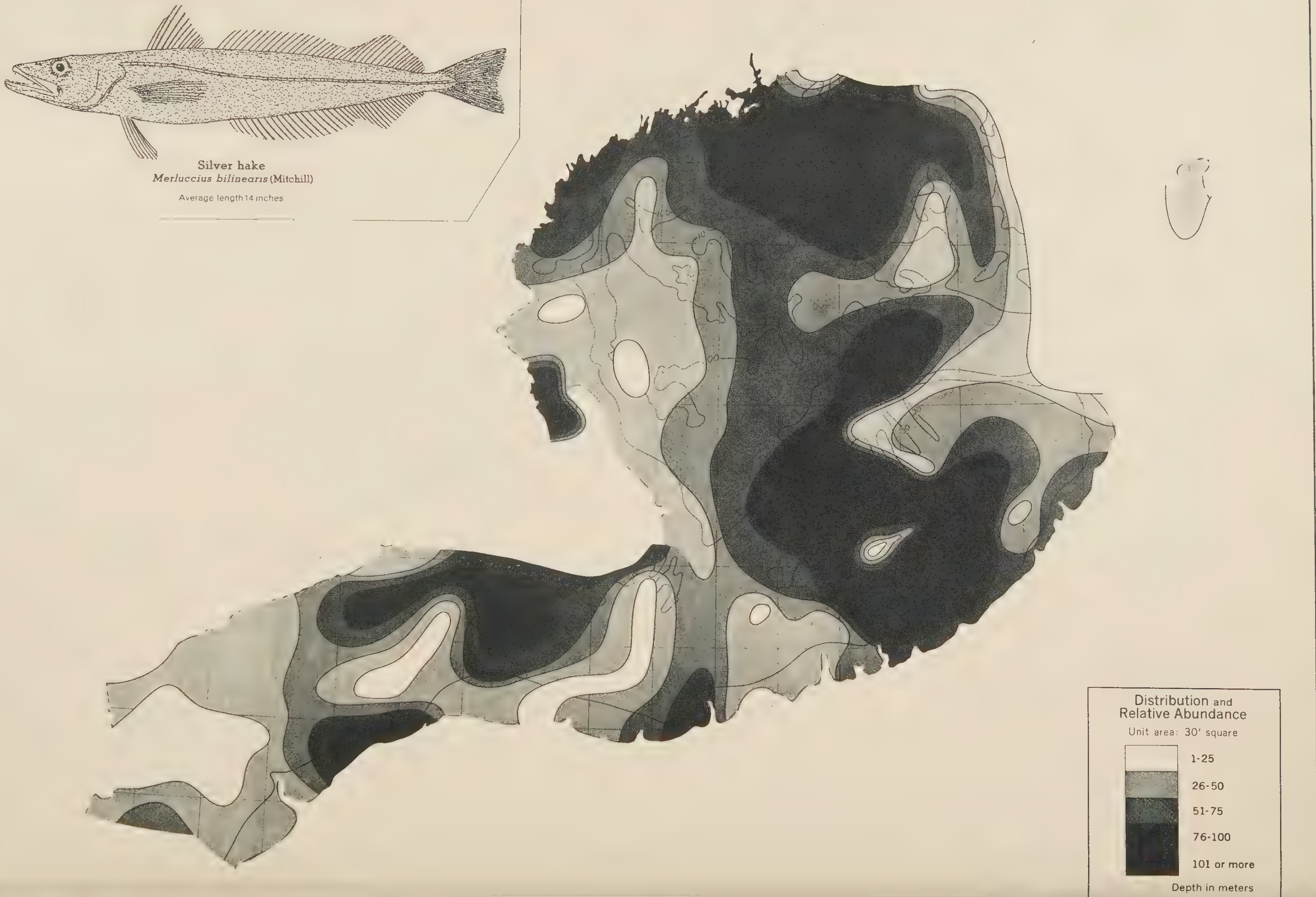

74°
72°
70°
68°
Distribution and Relative Abundance
Unit area: 18' square
1-5
6-50
51-100
101-200
201 or more
200 Depth in meters
200
NOMINAL SCALE 1:2,500,000

**Argentine**
*Argentina silus* (Ascanius)
Average length 12 inches

*Lithographed by Princeton Polychrome Press, Princeton, N.J.*

PLATE 5

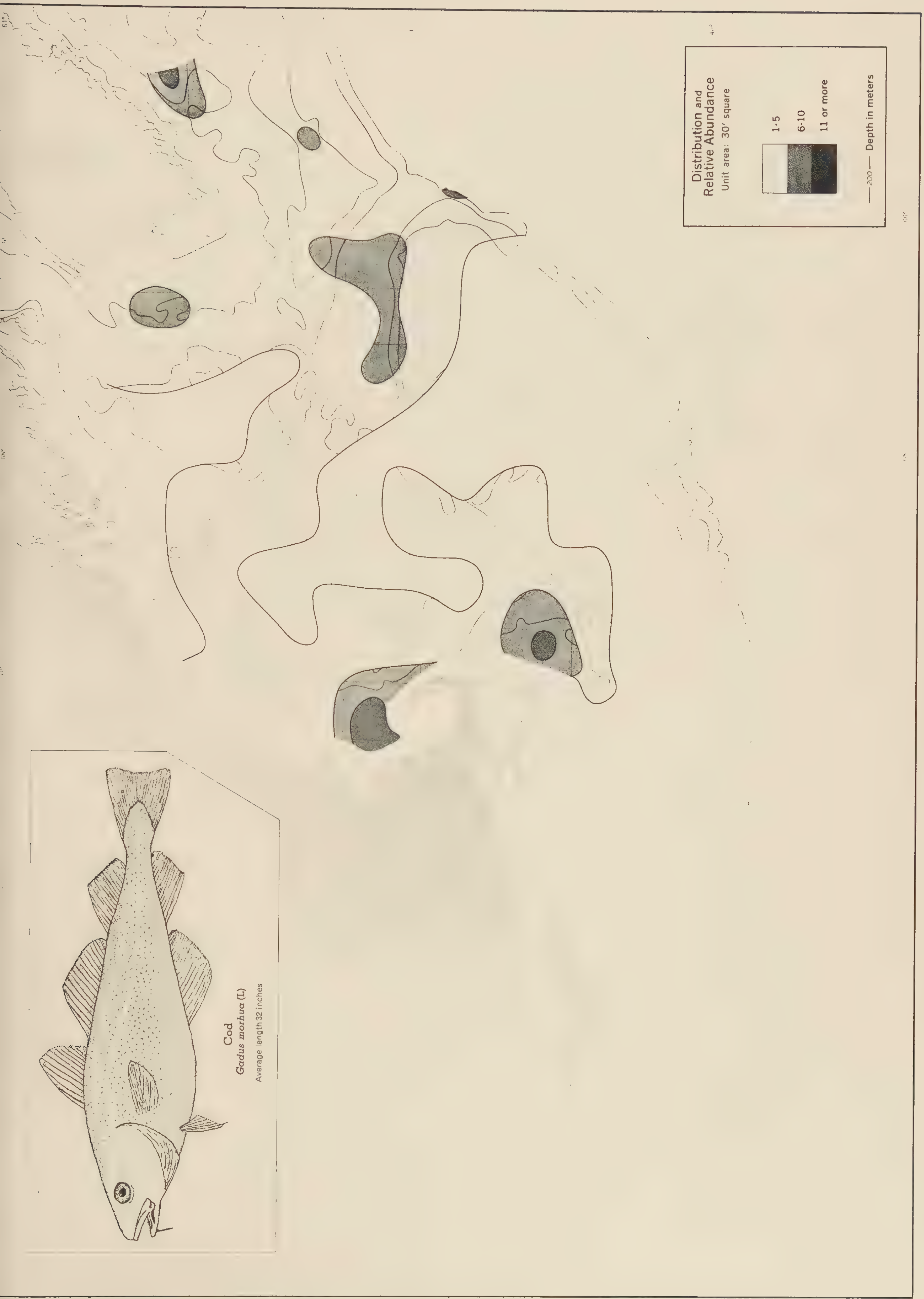
# SILVER HAKE



**Silver hake**
*Merluccius bilinearis* (Mitchill)
Average length 14 inches

Distribution and Relative Abundance
Unit area: 30′ square
1-25
26-50
51-75
76-100
101 or more
Depth in meters

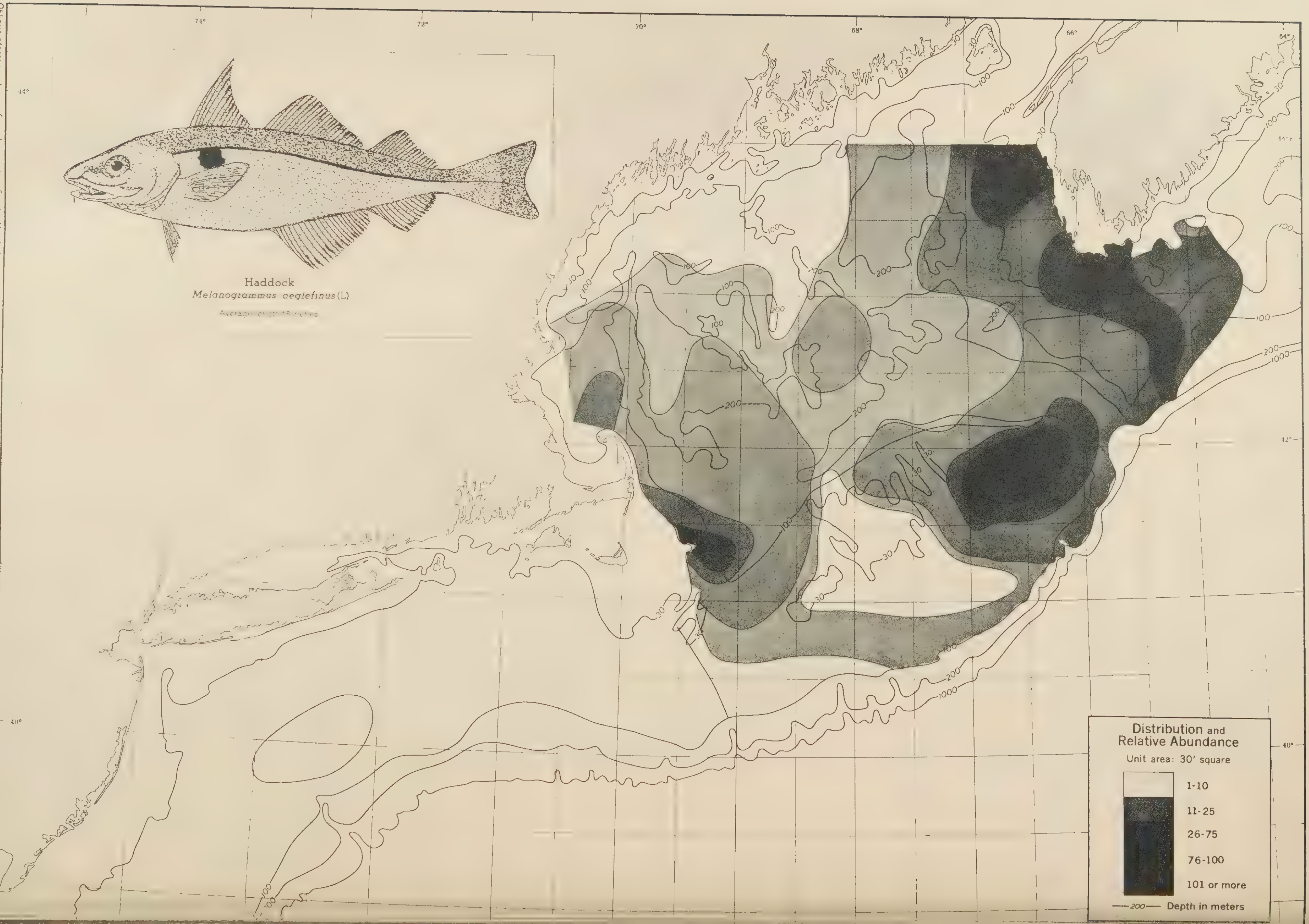
*Oblique stereographic conformal projection for the North Atlantic, center 54°N. 38°W*


Distribution and Relative Abundance
Unit area: 30′ square
▢ 1-5
▨ 6-10
■ 11 or more
—200— Depth in meters
Cod
*Gadus morhua* (L)
Average length 32 inches
NOMINAL SCALE 1:2,500,000

*Lithographed by Princeton Polychrome Press, Princeton, N.J.*

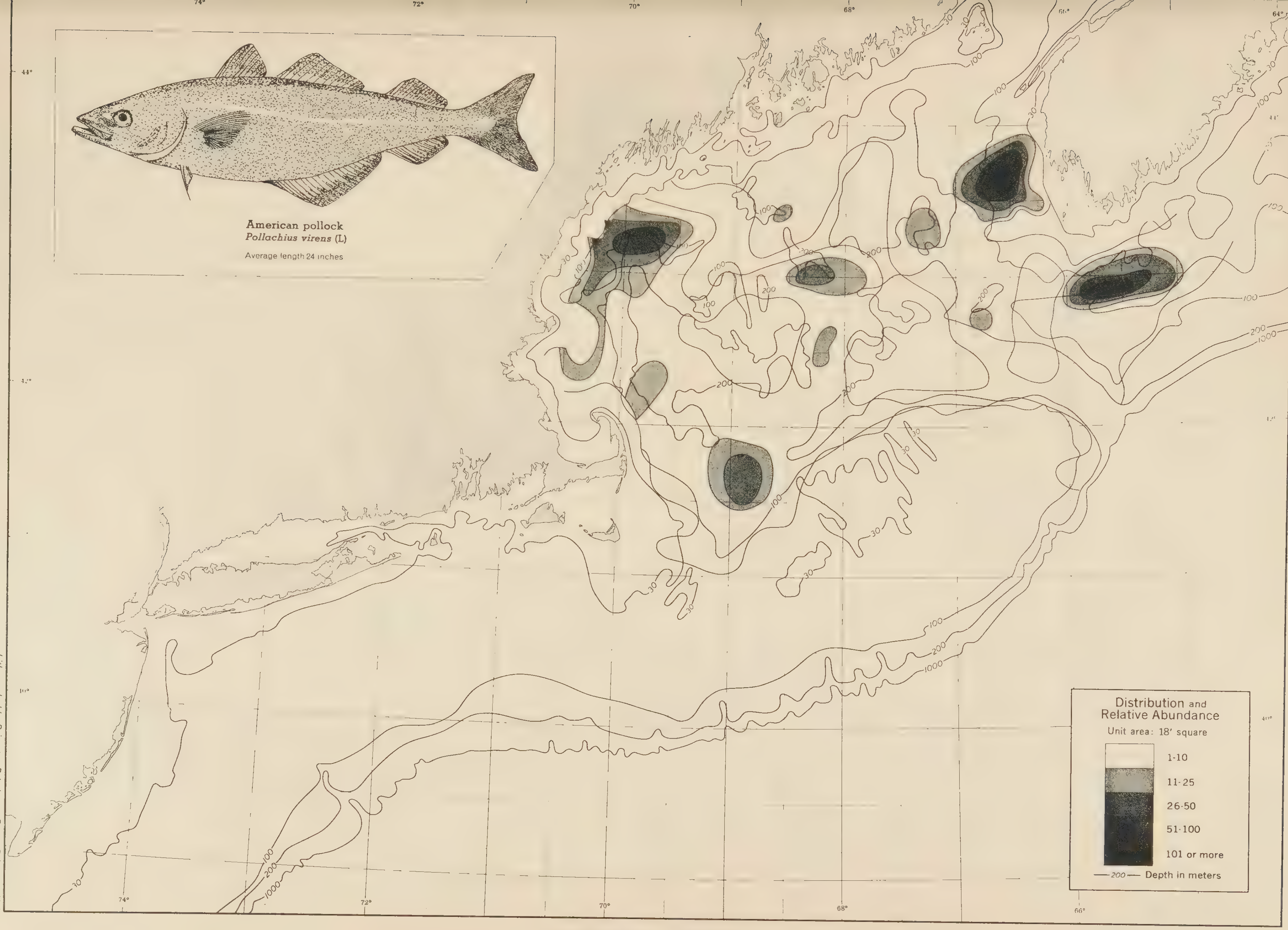
# HADDOCK

## PLATE 7


74°
72°
70°
68°
66°
64°
44°
42°
40°
30
100
200
1000
Distribution and Relative Abundance
Unit area: 30′ square
1-10
11-25
26-75
76-100
101 or more
200 Depth in meters

Haddock
*Melanogrammus aeglefinus* (L)
Average length 18 inches

*Oblique stereographic conformal projection for the North Atlantic, center 54°N 4° W*


74°
72°
70°
68°
66°
64°
44°
42°
40°
30
100
200
1000
Distribution and Relative Abundance
Unit area: 18′ square
1-10
11-25
26-50
51-100
101 or more
200 — Depth in meters

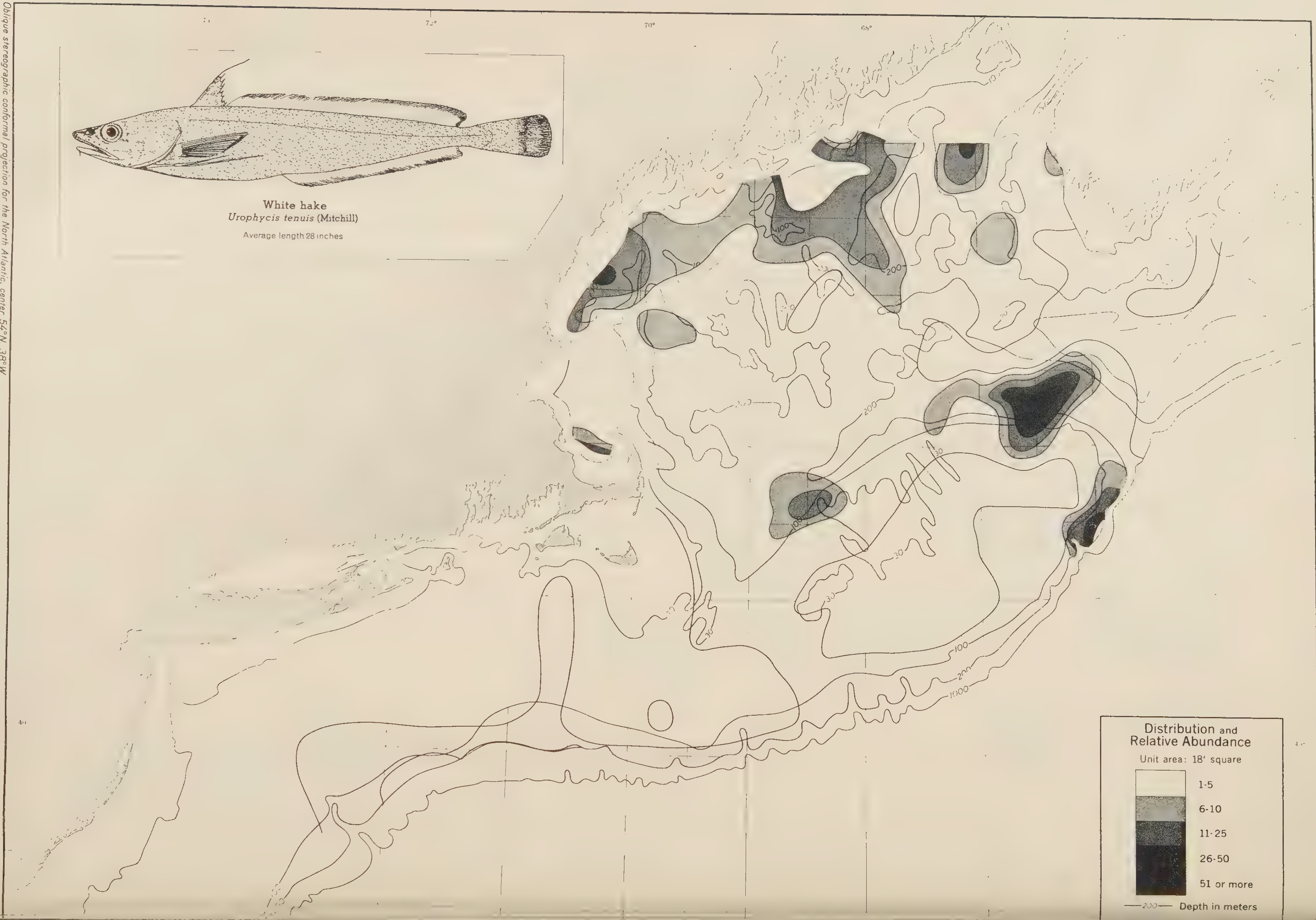
American pollock
*Pollachius virens* (L)
Average length 24 inches

NOMINAL SCALE 1:2,500,000

*Lithographed by Princeton Polychrome Press, Princeton, N.J.*

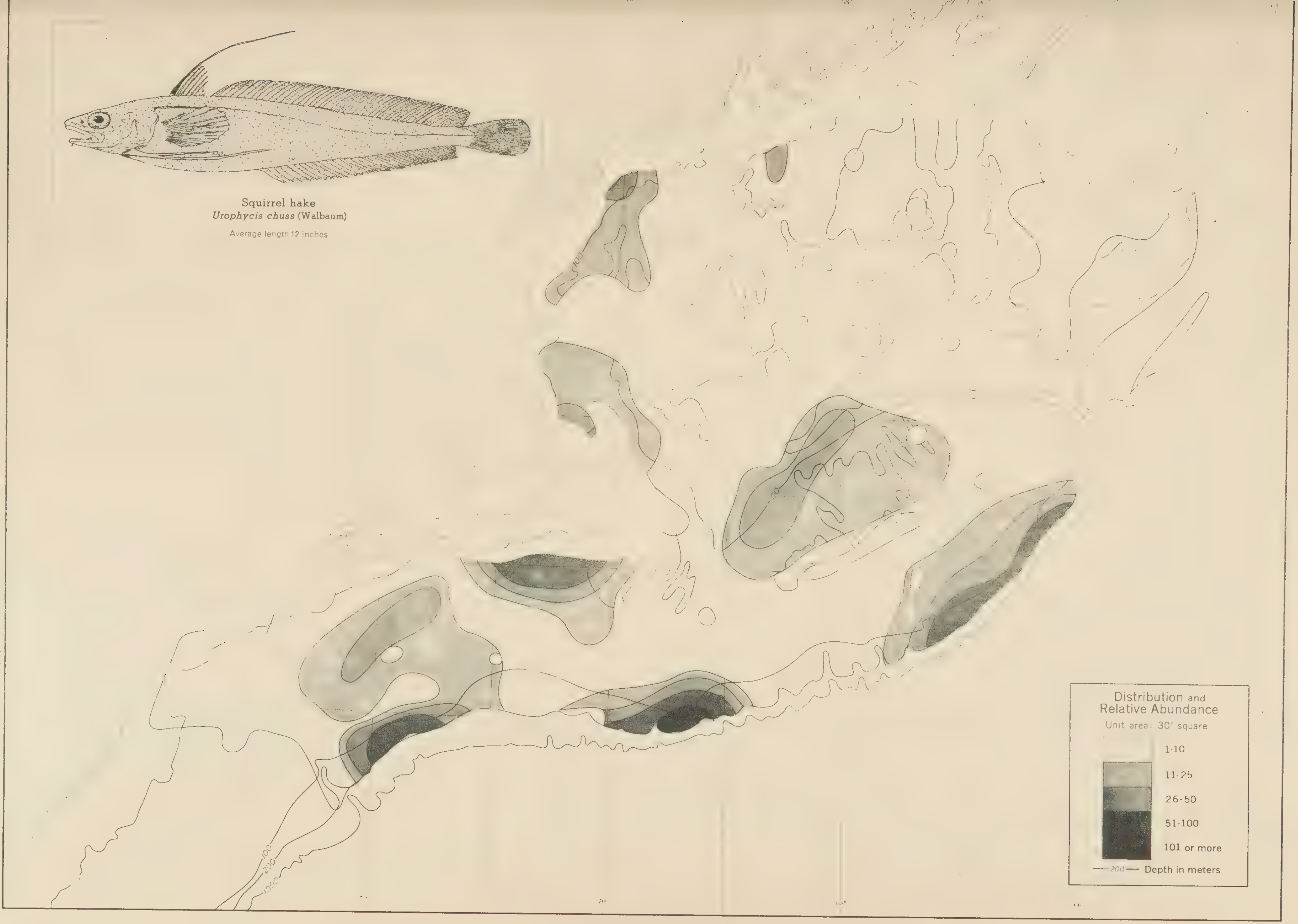
# WHITE HAKE

PLATE 9


72°
70°
Distribution and Relative Abundance
Unit area: 18' square
1-5
6-10
11-25
26-50
51 or more
200 Depth in meters
100
200
1000
30

White hake
*Urophycis tenuis* (Mitchill)
Average length 28 inches

*Oblique stereographic conformal projection for the North Atlantic, center 54°N. 38°W.*

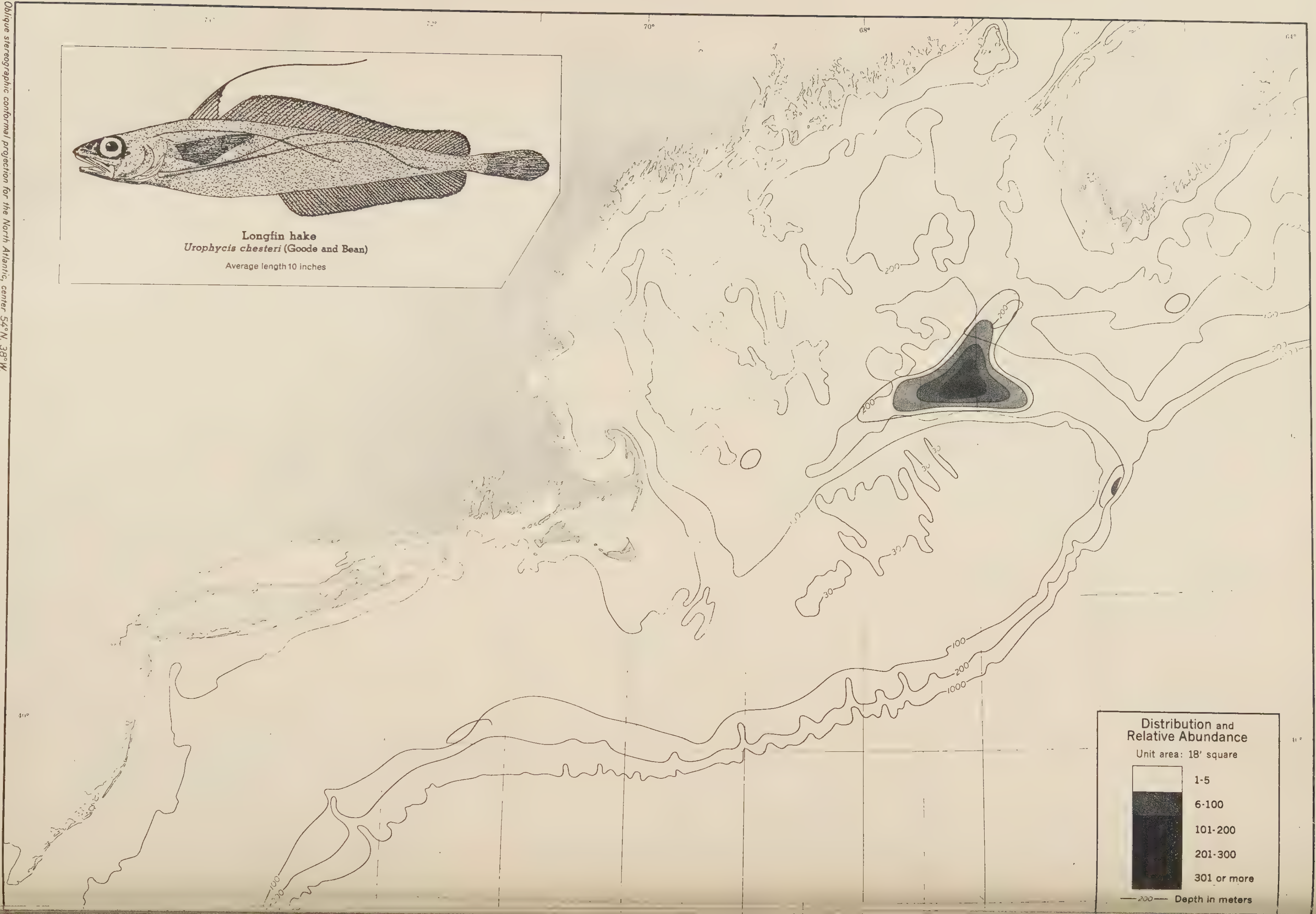

Squirrel hake
*Urophycis chuss* (Walbaum)
Average length 12 inches
100
200
1000
70
65°
Distribution and Relative Abundance
Unit area: 30′ square
1-10
11-25
26-50
51-100
101 or more
200 Depth in meters

NOMINAL SCALE 1:2,500,000

*Lithographed by Princeton Polychrome Press, Princeton, N.J.*

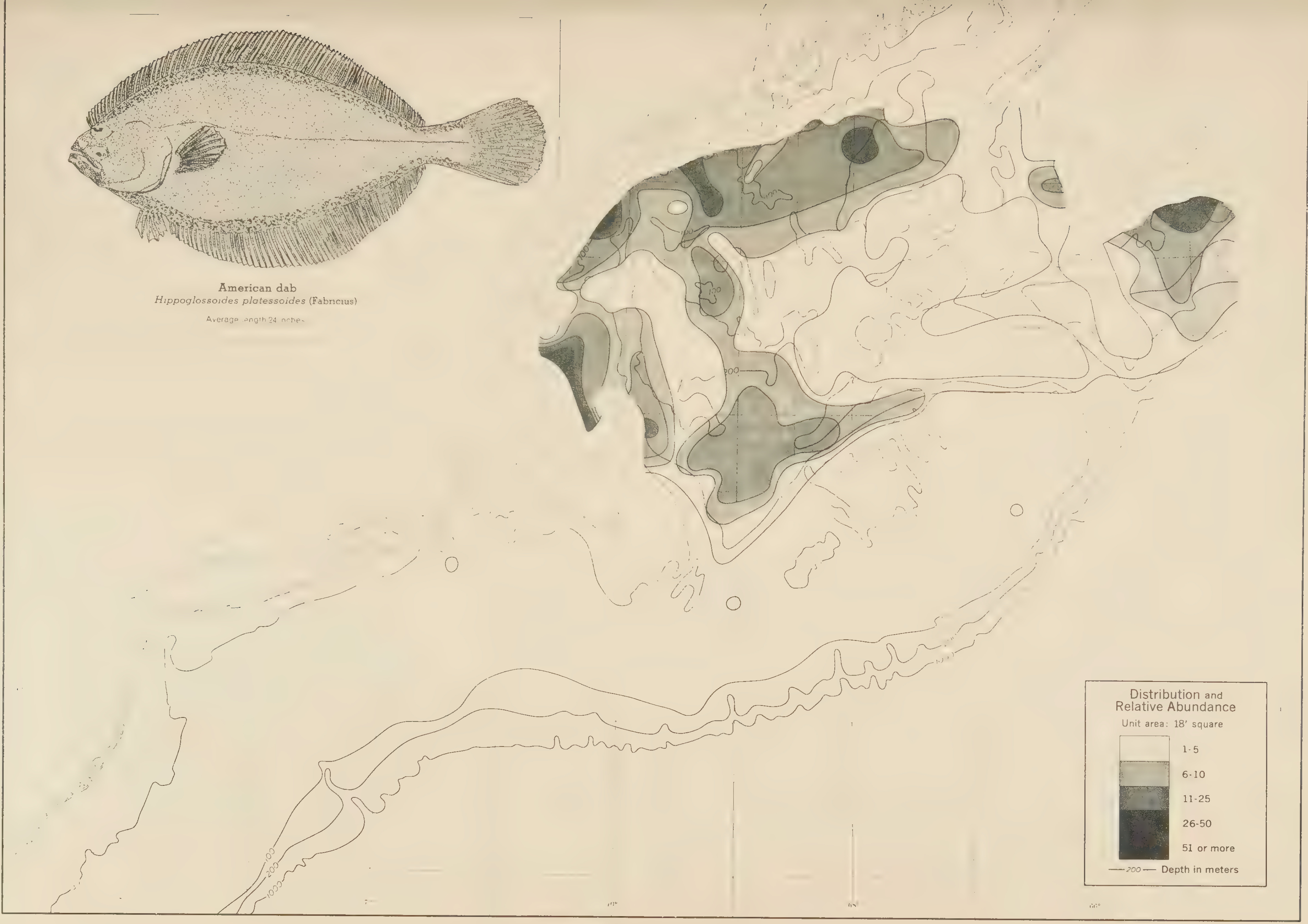
PLATE 11

# LONG-FINNED HAKE


72°
70°
68°
200
100
30
1000
Distribution and Relative Abundance
Unit area: 18′ square
1-5
6-100
101-200
201-300
301 or more
200 Depth in meters

**Longfin hake**
*Urophycis chesteri* (Goode and Bean)
Average length 10 inches

*Oblique stereographic conformal projection for the North Atlantic, center 54°N. 38°W.*


Distribution and Relative Abundance
Unit area: 18′ square
1-5
6-10
11-25
26-50
51 or more
200 Depth in meters
100
200
1000

American dab

*Hippoglossoides platessoides* (Fabricius)

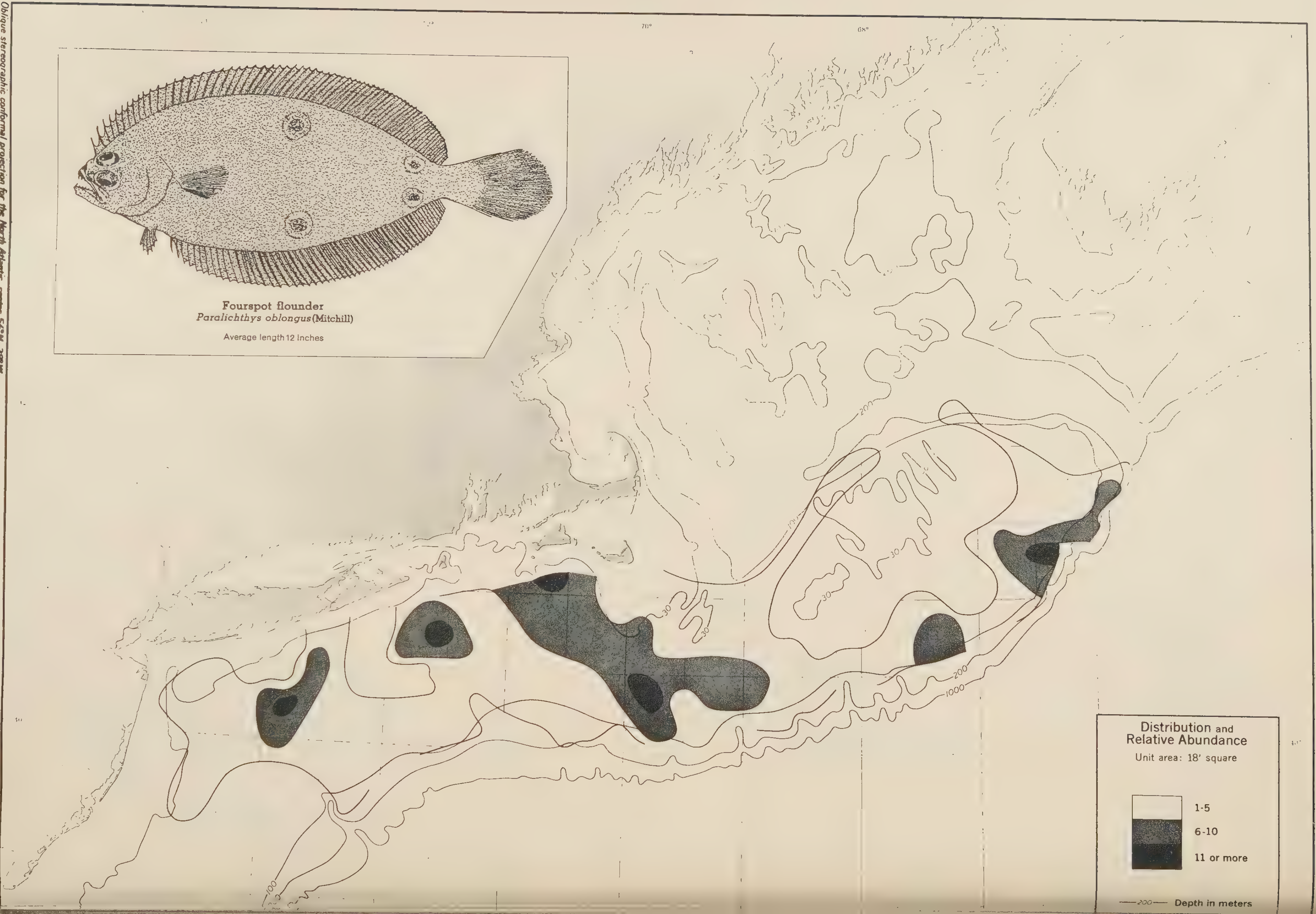
Average length 24 inches

NOMINAL SCALE 1:2,500,000

*Lithographed by Princeton Polychrome Press, Princeton, N.J.*

# FOUR-SPOTTED FLOUNDER

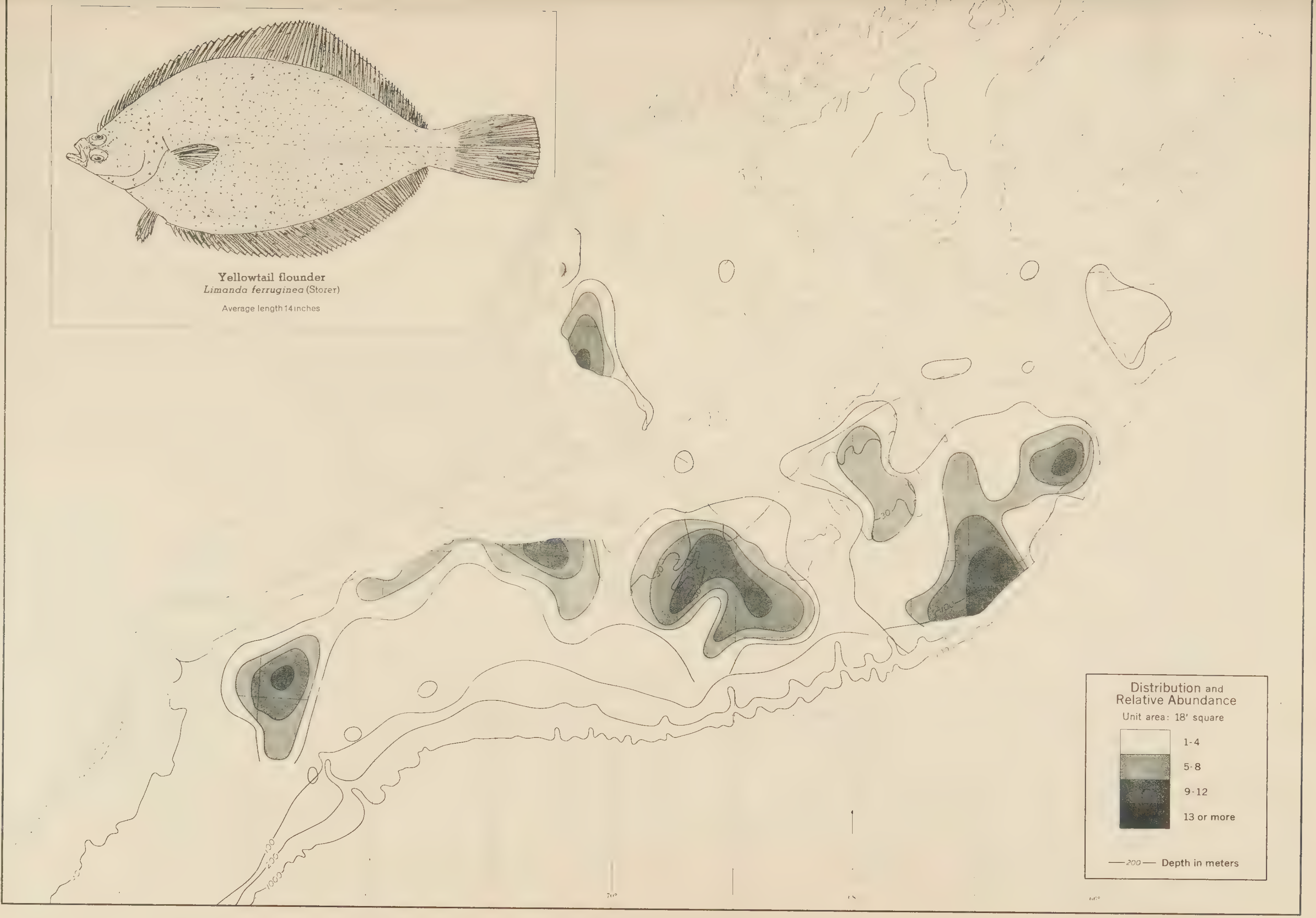
PLATE 13



Fourspot flounder
*Paralichthys oblongus* (Mitchill)
Average length 12 inches

Distribution and Relative Abundance
Unit area: 18' square
1-5
6-10
11 or more
200 Depth in meters
200
1000
100
30
76°
68°

*Oblique stereographic conformal projection for the North Atlantic, center 54° N. 38° W.*



Yellowtail flounder
*Limanda ferruginea* (Storer)
Average length 14 inches

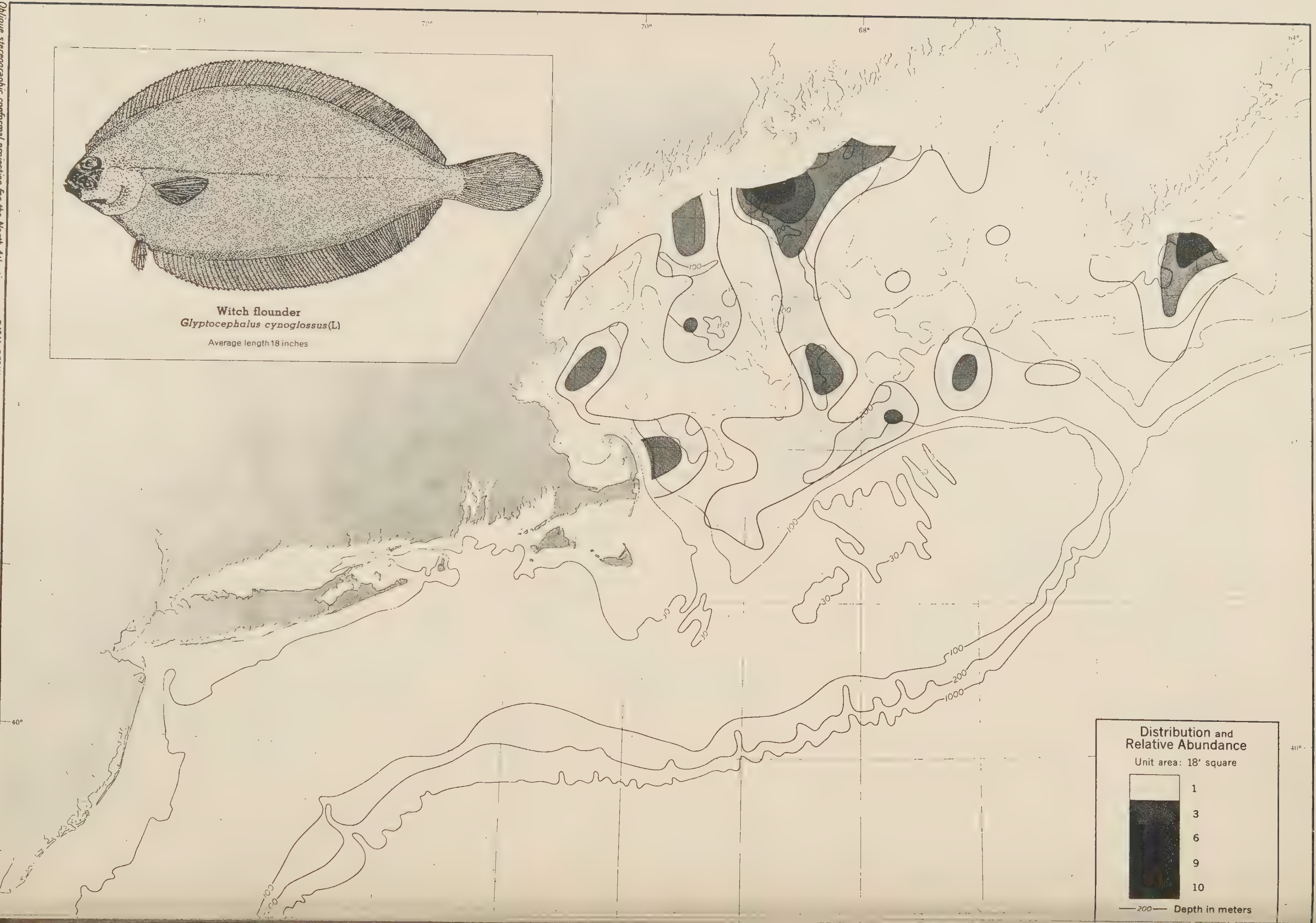
Distribution and Relative Abundance
Unit area: 18' square
1-4
5-8
9-12
13 or more
200 — Depth in meters
30
30
30
100
100
200
1000

NOMINAL SCALE 1:2,500,000

Lithographed by Princeton Polychrome Press, Princeton, N.J.

# WITCH FLOUNDER

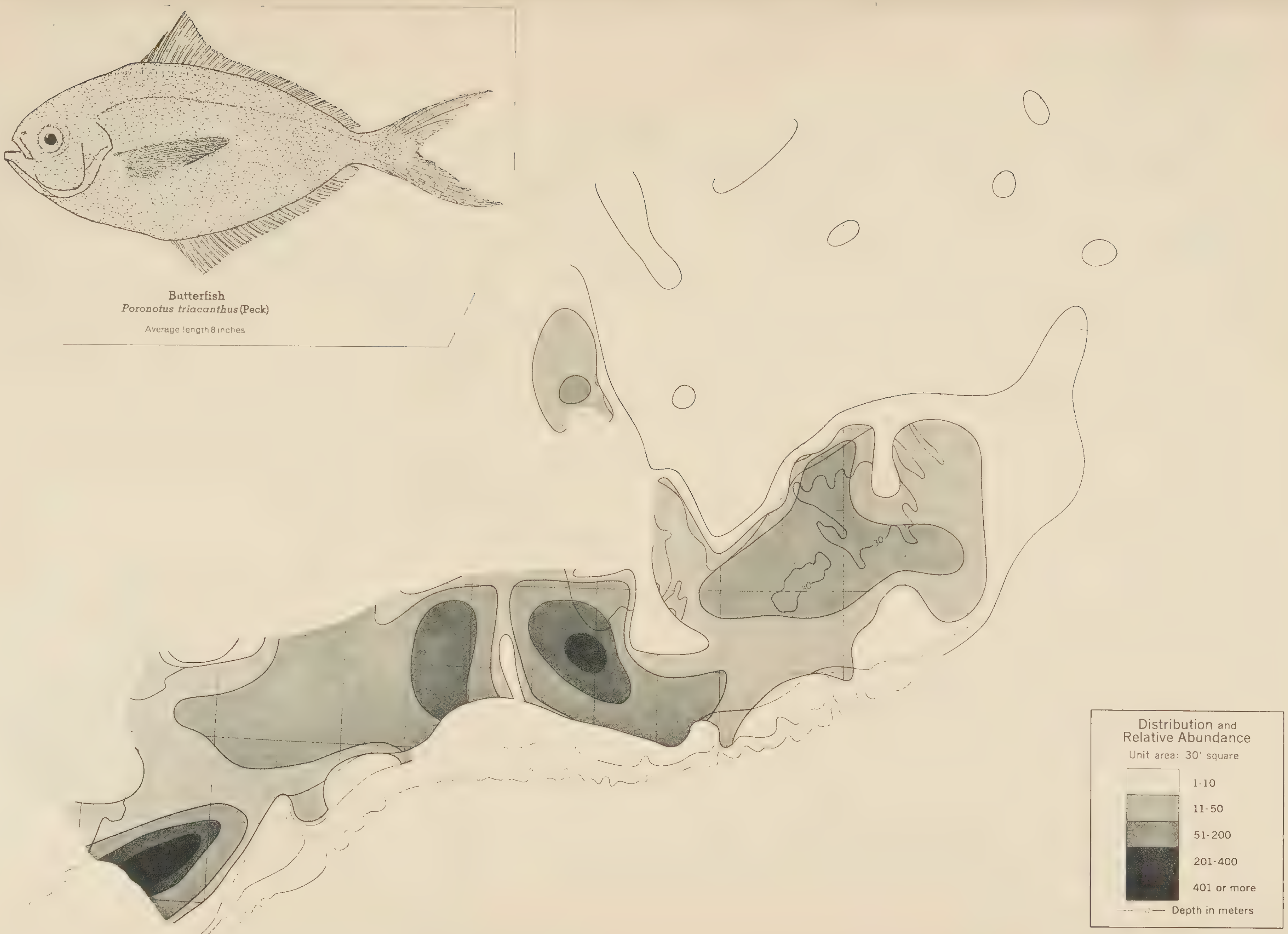
PLATE 15



Witch flounder
*Glyptocephalus cynoglossus* (L)
Average length 18 inches

Distribution and Relative Abundance
Unit area: 18′ square
1
3
6
9
10
200 Depth in meters
70°
68°
40°
30
100
200
1000

*Oblique stereographic conformal projection for the North Atlantic, center 54°N. 38°W.*



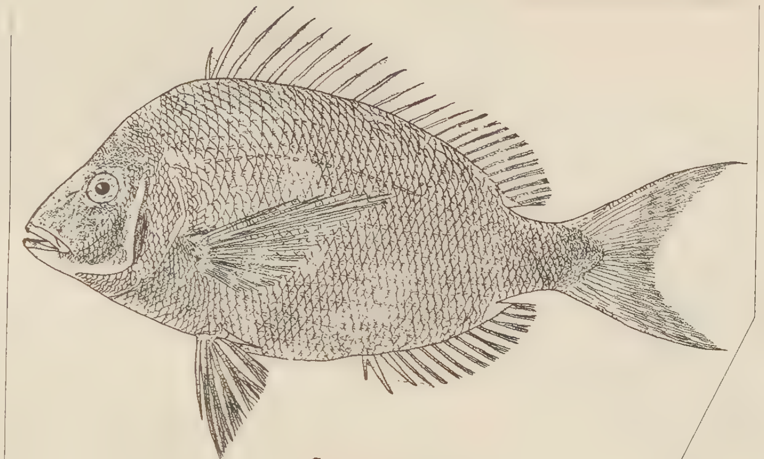
**Butterfish**
*Poronotus triacanthus* (Peck)

Average length 8 inches

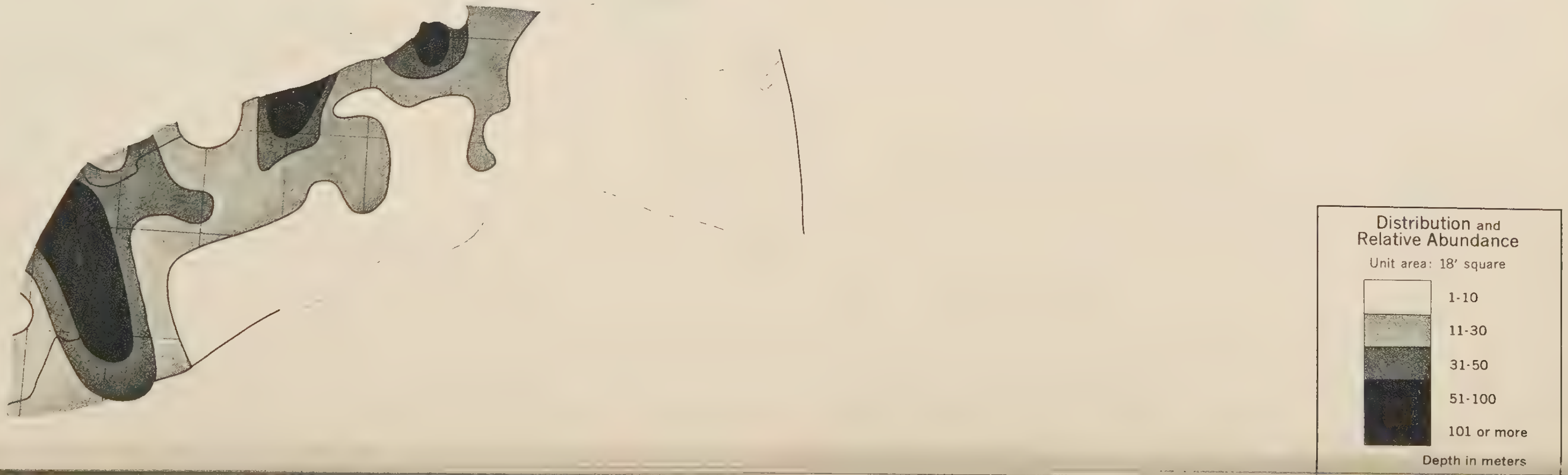
Distribution and
Relative Abundance
Unit area: 30′ square
1-10
11-50
51-200
201-400
401 or more
Depth in meters
30
30

NOMINAL SCALE 1:2,500,000

Lithographed by Princeton Polychrome Press, Princeton, N.J.

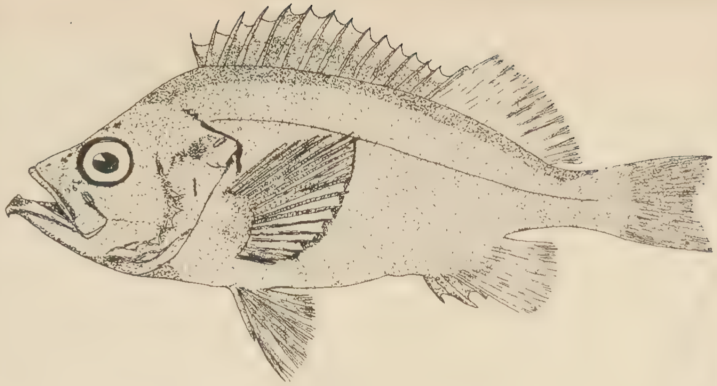


Scup
*Stenotomus versicolor* (Mitchill)
Average length 10 inches



Distribution and Relative Abundance
Unit area: 18′ square
1-10
11-30
31-50
51-100
101 or more
Depth in meters

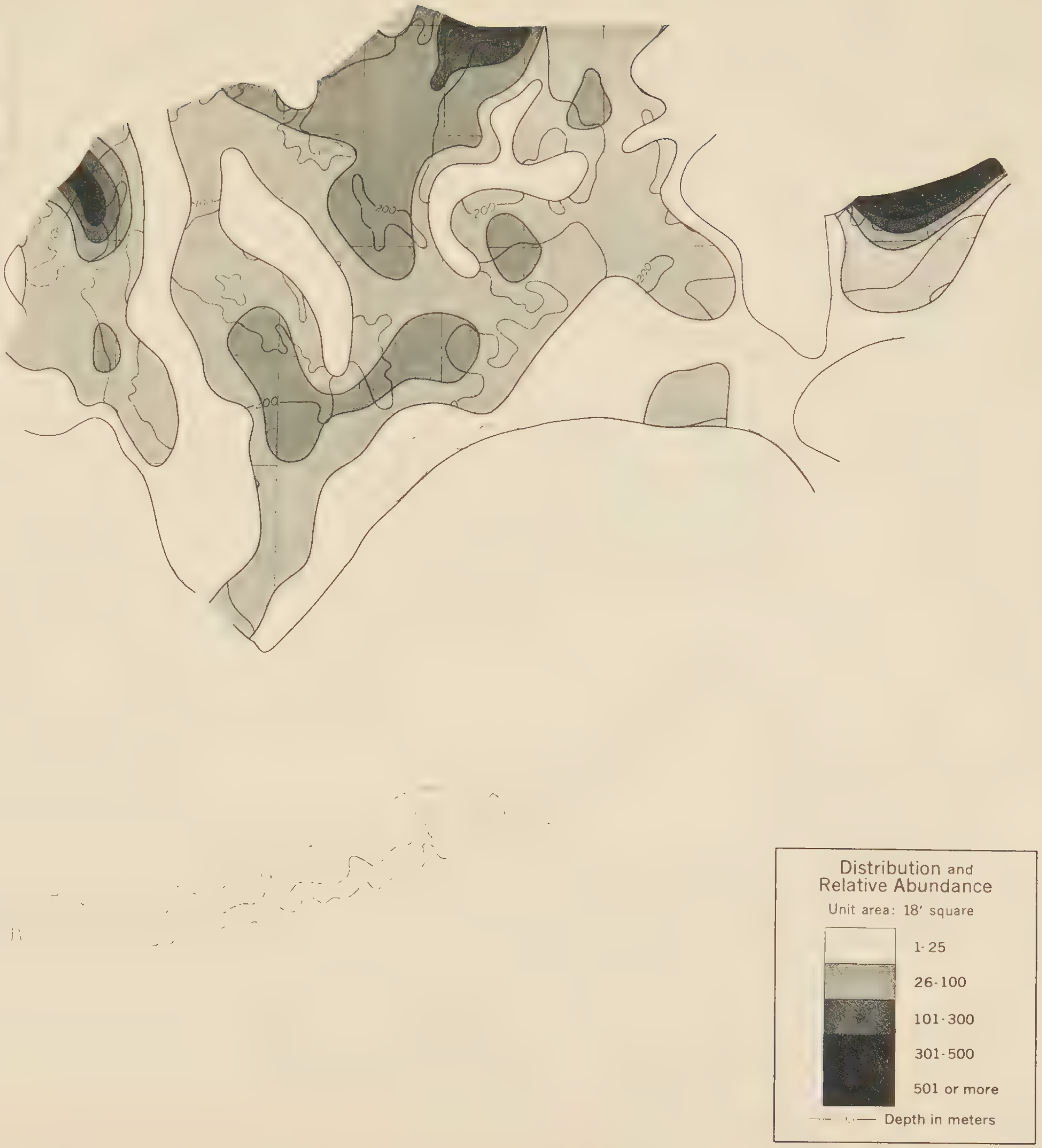
*Oblique stereographic conformal projection for the North Atlantic, center 54°N. 38°W.*



Redfish

*Sebastes marinus* (L)

Average length 12 inches

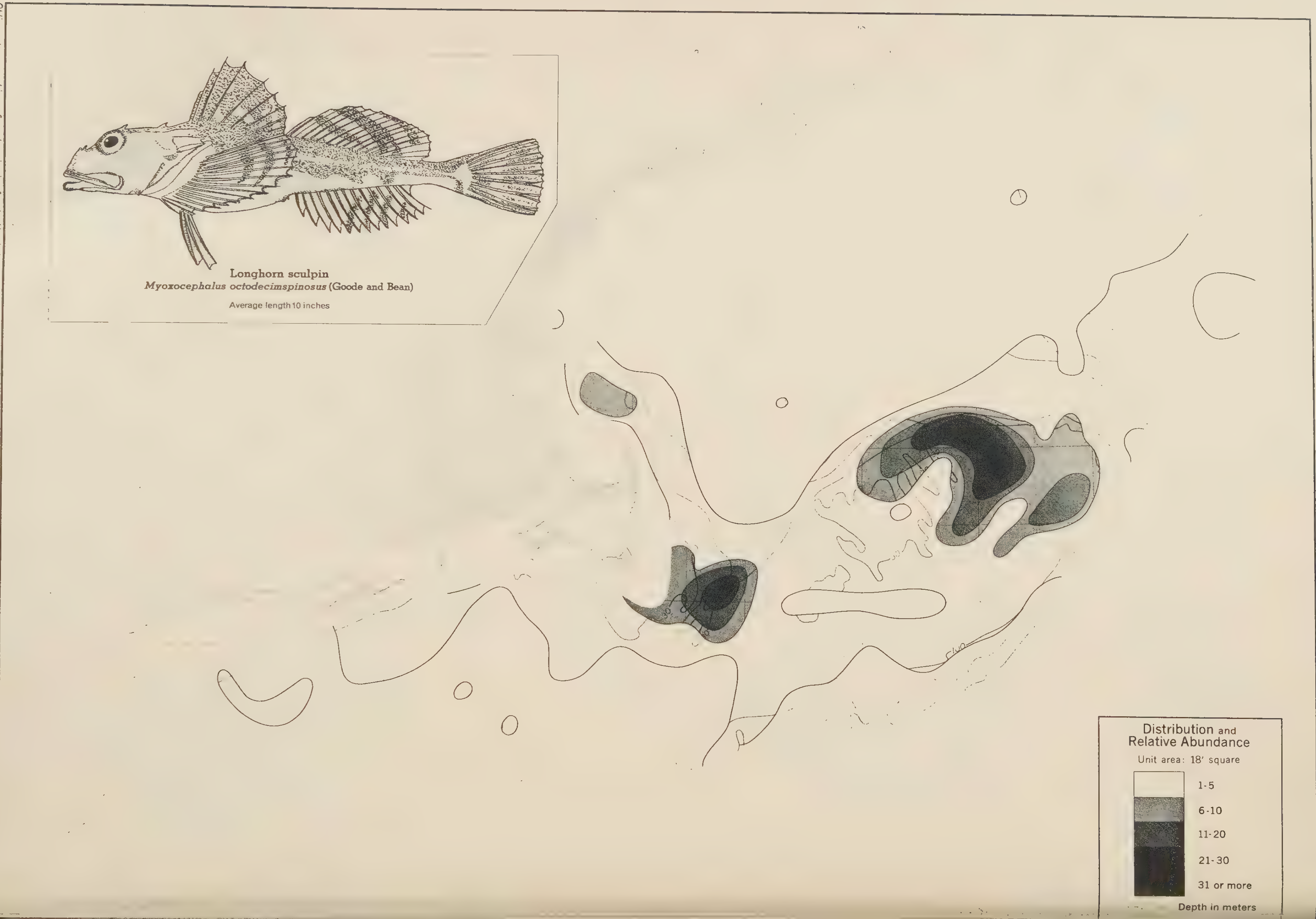


200
Distribution and Relative Abundance
Unit area: 18′ square
1-25
26-100
101-300
301-500
501 or more
Depth in meters

NOMINAL SCALE 1:2,500,000

*Lithographed by Princeton Polychrome Press, Princeton, N.J.*

# LONGHORN SCULPIN



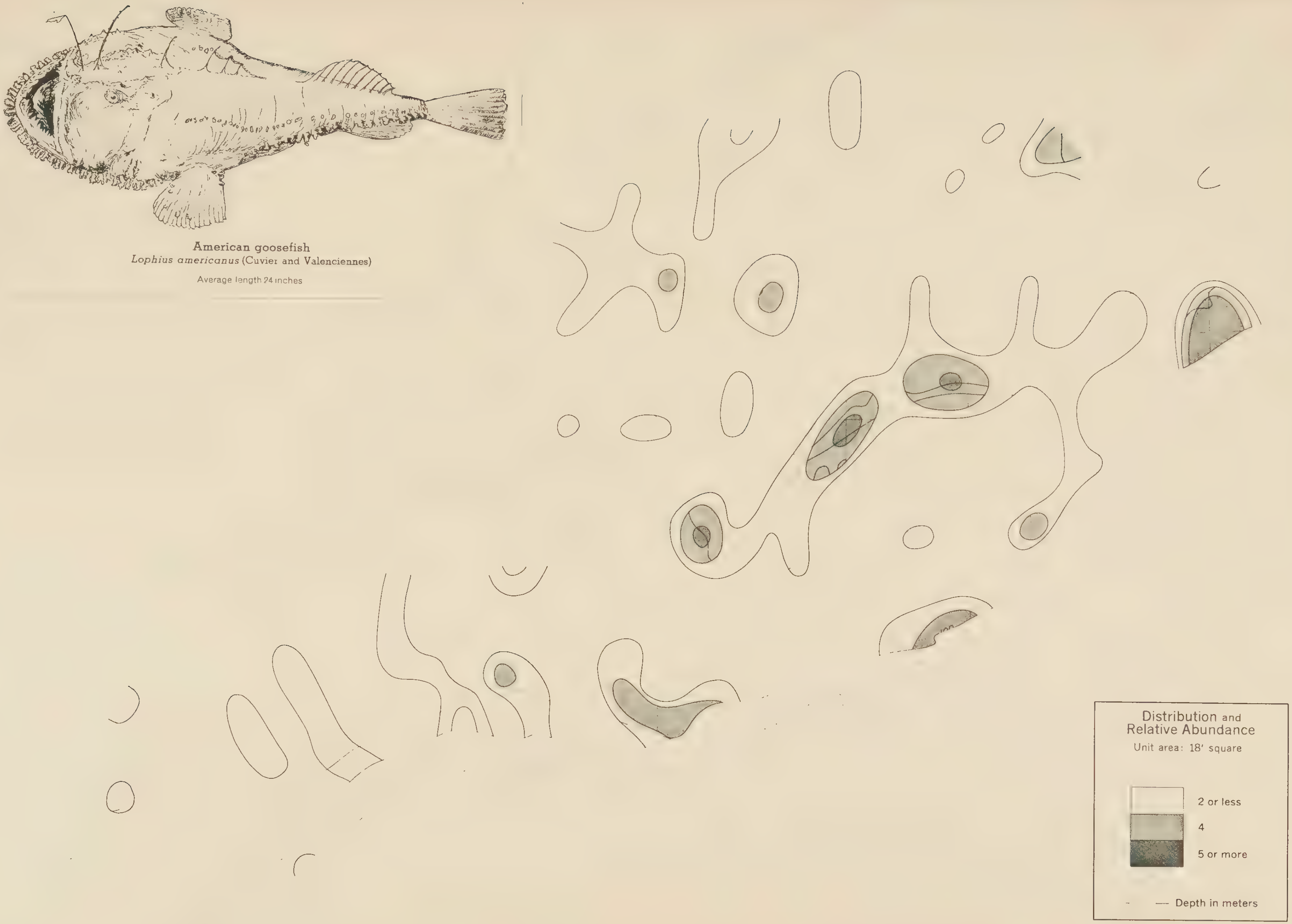
Longhorn sculpin

*Myoxocephalus octodecimspinosus* (Goode and Bean)

Average length 10 inches

Distribution and Relative Abundance
Unit area: 18′ square
1-5
6-10
11-20
21-30
31 or more
Depth in meters

*Oblique stereographic conformal projection for the North Atlantic, center 54°N. 38°W.*


Distribution and
Relative Abundance
Unit area: 18′ square
2 or less
4
5 or more
Depth in meters

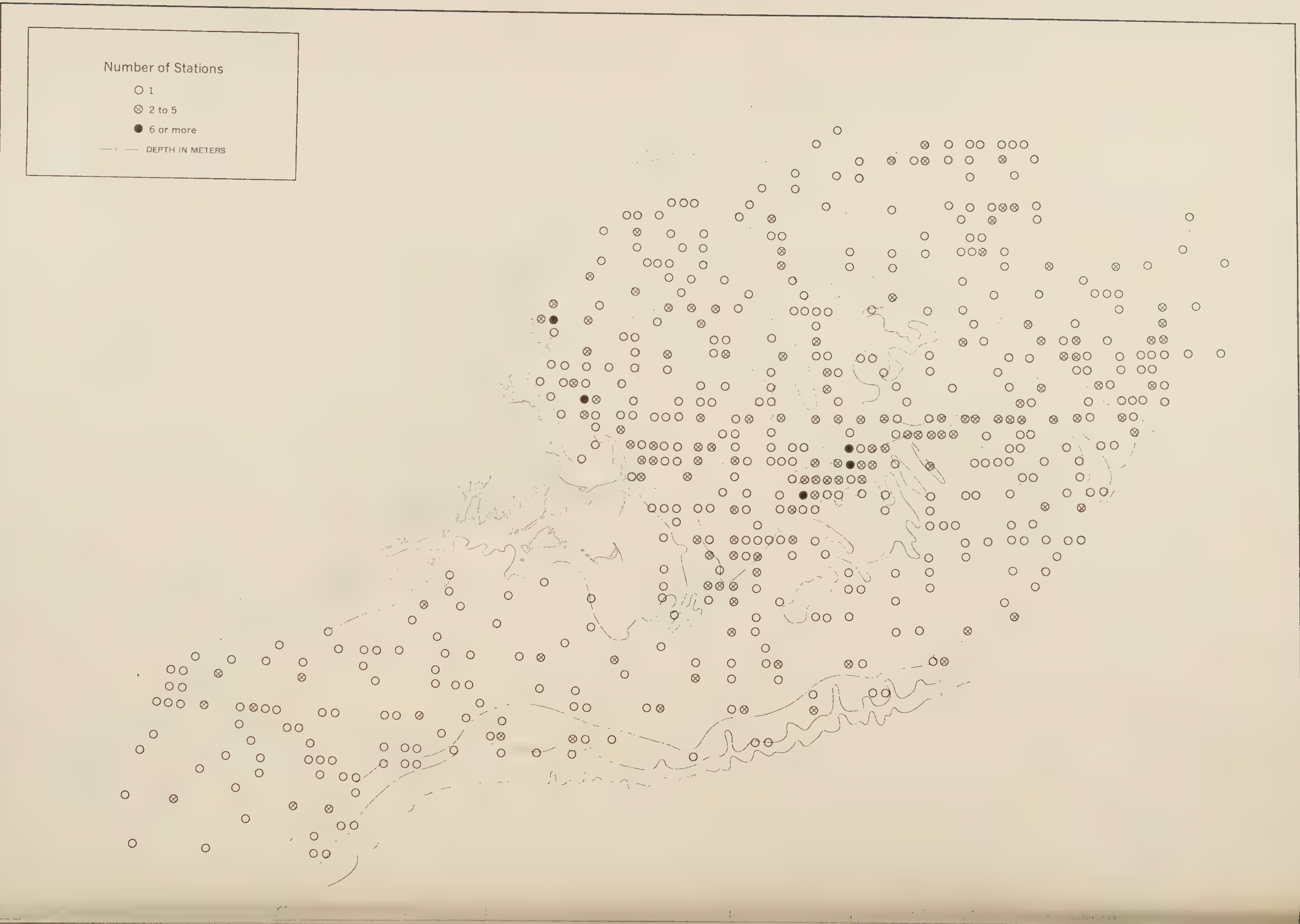
American goosefish
*Lophius americanus* (Cuvier and Valenciennes)
Average length 24 inches

NOMINAL SCALE 1:2,500,000

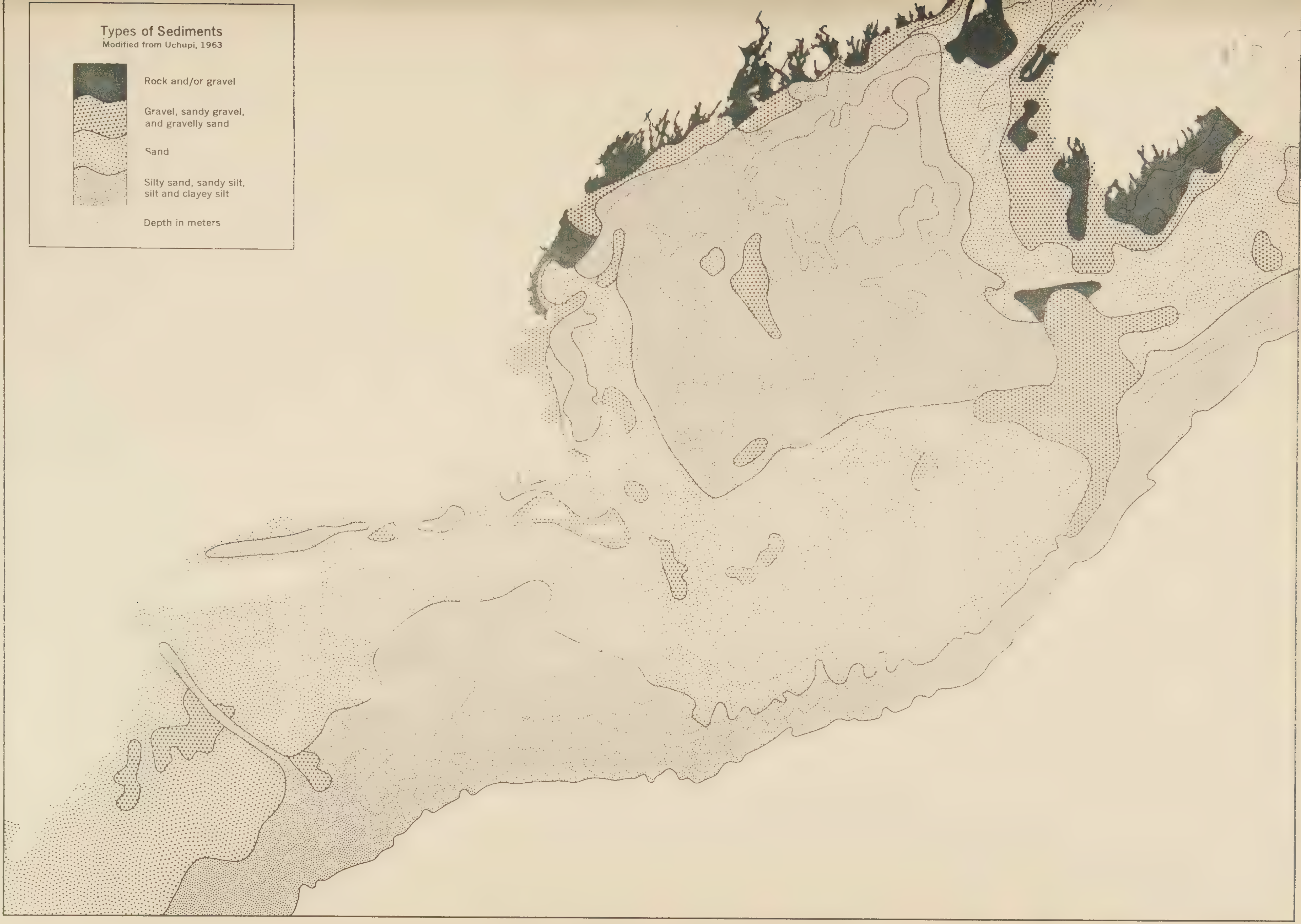
*Lithographed by Princeton Polychrome Press, Princeton, N.J.*

PLATE A

# SAMPLING INTENSITY


Number of Stations
○ 1
⊗ 2 to 5
● 6 or more
DEPTH IN METERS

Oblique stereographic conformal projection for the North Atlantic, center 54°N. 38°W.


Types of Sediments
Modified from Uchupi, 1963
Rock and/or gravel
Gravel, sandy gravel, and gravelly sand
Sand
Silty sand, sandy silt, silt and clayey silt
Depth in meters

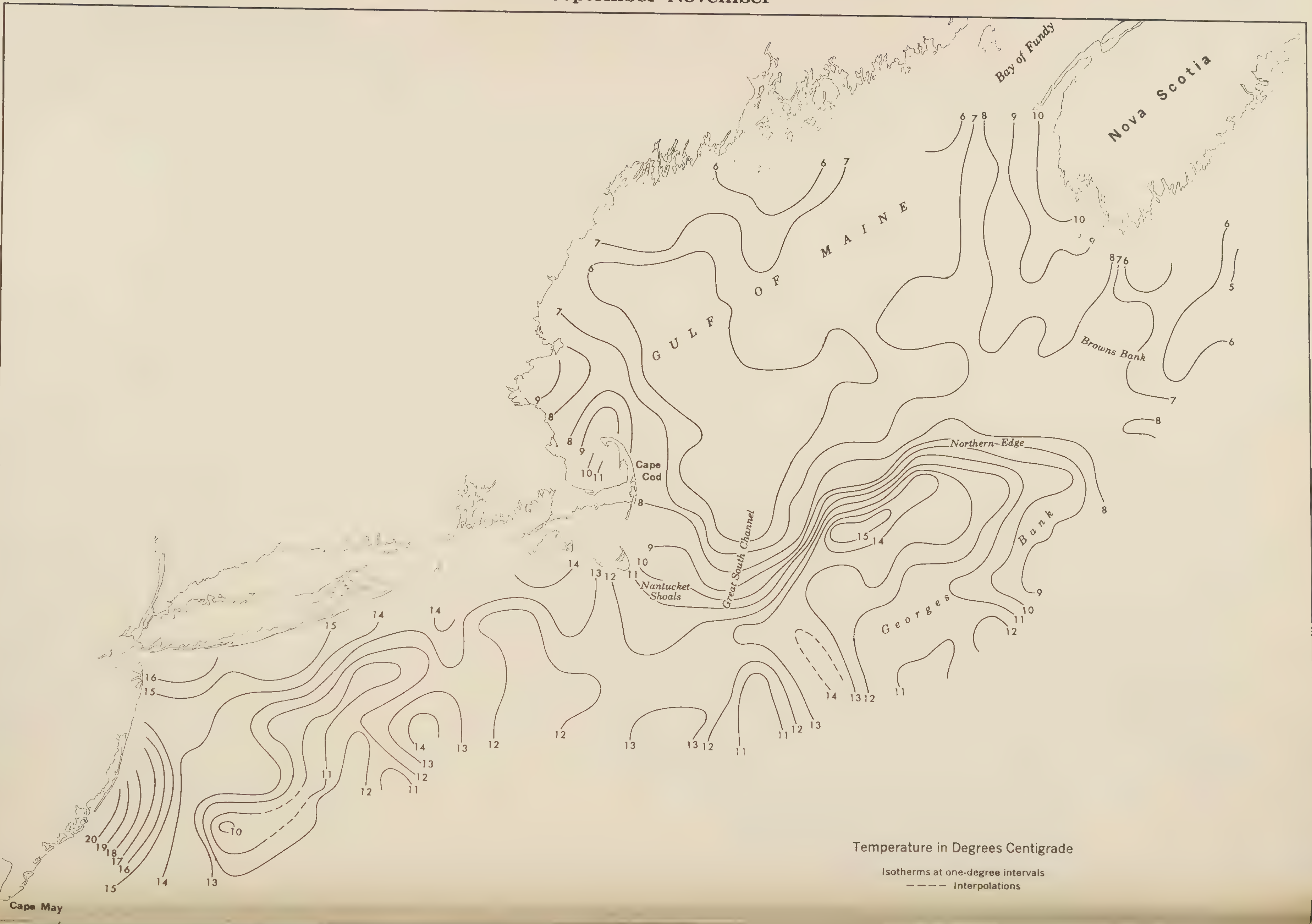
NOMINAL SCALE 1:2,500,000

*Lithographed by Princeton Polychrome Press, Princeton, N.J.*

PLATE C

# AVERAGE BOTTOM TEMPERATURES

## September - November


Nova Scotia
Bay of Fundy
GULF OF MAINE
Browns Bank
Northern-Edge
Georges Bank
Great South Channel
Nantucket Shoals
Cape Cod
Cape May
Temperature in Degrees Centigrade
Isotherms at one-degree intervals
– – – – Interpolations

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E-7

# ECOLOGY OF HERRING LARVAE IN THE COASTAL WATERS OF MAINE

By

Joseph J. Graham and Harold C. Boyar[1]

## ABSTRACT

The ecology of larval and juvenile herring, *Clupea harengus* (Linnaeus) in the coastal waters of the Gulf of Maine is being studied at the U.S. Bureau of Commercial Fisheries Biological Laboratory, Boothbay Harbor, Maine. This report is the first of a series and covers a period of a year beginning June, 1961. Hydrographic and biological observations were made in three embayments located along the central Maine coast; the Sheepscot, Boothbay and Damariscotta. Major seasonal environmental events were similar in the three areas. Average conditions for the year were somewhat different; eastward from the Sheepscot to the Boothbay and Damariscotta areas, average seasonal salinities, surface temperatures and surface standing crops of zooplankton increased. Meter-net catches showed marked differences in the seasonal and areal distribution of herring larvae. The seasonal distribution of herring larvae was inverse to other fish larvae. The source of the herring larvae, the influence of avoidance and migration by larval herring on meter net catches and the utilization of the estuarine environment during their larval stages are discussed.

## INTRODUCTION

The U.S. Bureau of Commercial Fisheries Biological Laboratory, Boothbay Harbor, Maine, is studying the ecology of larval and juvenile herring, *Clupea harengus* (Linnaeus), in the coastal waters of the Gulf of Maine. The study is designed to determine trends in the distribution and abundance of the early life history stages of herring and their relation to variations in the environment. This is the first of a series of reports and covers the period from June 1961 to June 1962. The region investigated, an inshore habitat, is part of the rocky coast of Maine which is deeply embayed and dissected by drowned river valleys (Fig. 1). The sides of the lower estuaries and bays are usually steep and their basins relatively deep, the water is well mixed, and dilution evident only during periods of peak river discharge. Within the bays and lower estuaries, water exchange is influenced by the presence of islands and ledges in the areas of deep water, and by narrow guts (or passages).

The general ecology of the lower Sheepscot River estuary has been described by Stickney (1959) and a specific study of the bottom fauna has been made by Robert W. Hanks, whose paper, "A benthic community in a New England estuary", is in press in the Fishery Bulletin series of the U.S. Fish and Wildlife Service. The Sheepscot River has a drainage area of approximately 148 sq. mi. and an average daily discharge of 239 c.f.s. (U.S. Geological Survey, 1962, 1962*a*). During the study period, 83,840 c.f.s. was discharged by the river, with the highest monthly discharge (36% of the total) in April and the lowest(2%) in September. A secondary high (14%) and a low (3%) occurred during December and February, respectively. Similar data were not available for the Damariscotta River basin which is smaller than the Sheepscot. The Boothbay area does not receive discharge from any major stream.

## METHODS AND MATERIALS

Each of the 18 stations shown in Fig. 1 was sampled biweekly, alternating hydrographic and fishing cruises. Weather conditions occasionally hampered sampling but of 26 cruises, only 5 were not completed and no more than 5 stations were abandoned on any one cruise. There were considerable variations in the sequence, stage of tide, and time of day that stations were sampled. These variations are not considered to detract from the average seasonal and areal data obtained. The sampling procedure is considered analagous to that of Hopkins (1963). He concluded that several tows spaced

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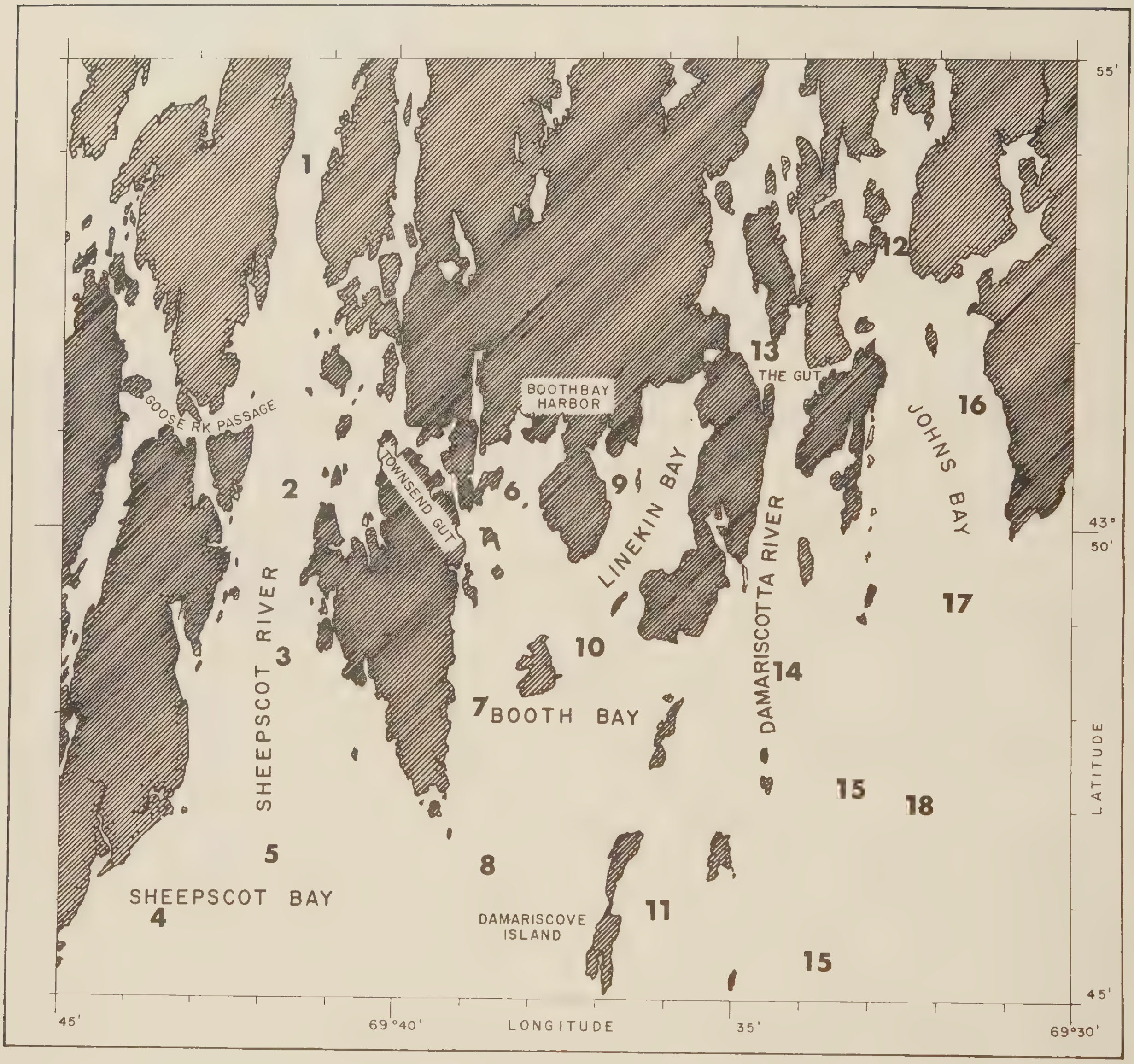
[1] U.S. Bureau of Commercial Fisheries Biological Laboratory, Boothbay Harbor, Maine, USA.



55'
43°
50'
45'
45'
69°40'
LONGITUDE
35'
69°30'
LATITUDE
GOOSE RK PASSAGE
TOWNSEND GUT
BOOTHBAY HARBOR
THE GUT
JOHNS BAY
LINEKIN BAY
DAMARISCOTTA RIVER
SHEEPSCOT RIVER
BOOTH BAY
SHEEPSCOT BAY
DAMARISCOVE ISLAND
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
15
16
17
18

Fig. 1. Sampling stations in the Sheepscot-Boothbay-Damariscotta region of Maine. Two positions are shown for station 15. Because of obstructions in the water the original station position was shifted midway during the year of sampling.

over a single tidal cycle were more effective in estimating average biological characteristics at a station than one that filtered a large amount of water in a single tow.

Bathythermograph casts, surface temperatures and appropriate meterological observations were made during all cruises. On hydrographic cruises, Nansen bottle casts were made at 0, 10 and 20 m and just above the bottom. Plankton tows were made at the surface and vertically from the bottom. On fishing cruises an otter trawl with a 25-ft mouth opening and cod end liner (fine mesh) was towed along the bottom. The mesh at the mouth had a stretched measure of 4.4 cm; and the cod end, 3.2 cm. Sampling of salinity and plankton was confined to the surface. The 1-m plankton net used to capture

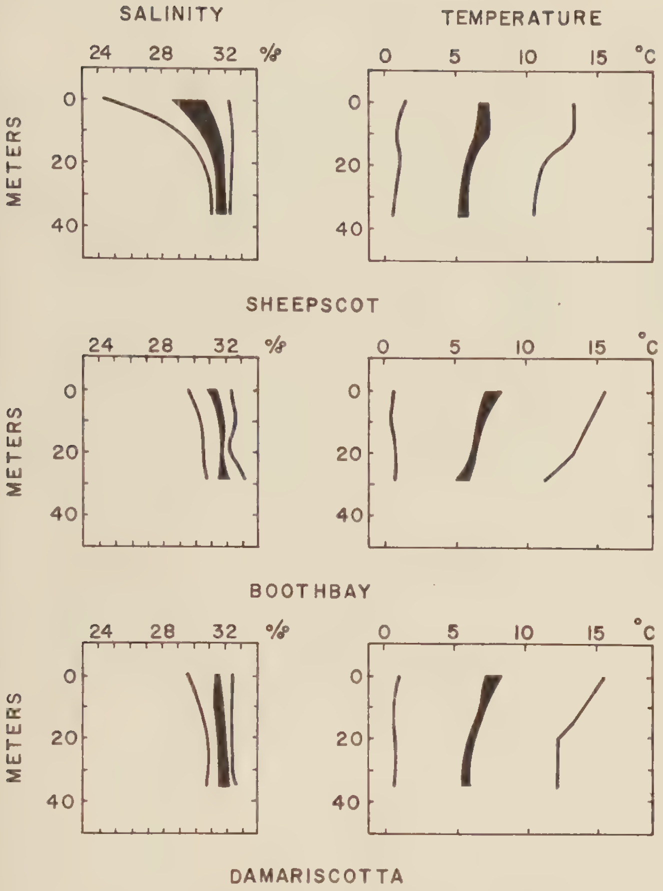


Fig. 2. Annual means and extremes of temperature and salinity. The mean range for each area at various depths is shaded.

larvae and plankton had a 0.51 mm mesh opening with 13 meshes per linear centimeter; no flowmeter was used during tows on station. The column of water strained on a vertical tow depended upon the depth of water. The amount strained during surface tows was determined by a calibrated Atlas flowmeter. The flowmeter was suspended in a meter net ring and towed over a known distance both with and without a net. This calibration, revolutions of the flowmeter per cubic meter of water strained, was applied with a net factor to metered tows. The average volume of water strained during the standard 10-min tow at 3 knots was 1,550 $m^3$.

In the laboratory, fish larvae were separated from plankton samples, identified and counted. Displacement volumes were calculated for the remaining plankton after removing foreign materials and organisms larger than 5 cm. Salinity samples were titrated by the Knudsen method.

## RESULTS

### Environmental conditions

Figure 2 summarizes, as profiles, the hydrographic data obtained during the year. The highest salinity values in each area were similar, reflecting a seasonal maximum in evaporation and a minimum of runoff common to the three areas. In the upper 20 m, Boothbay and Damariscotta were comparable, mean salinities were higher and their range less than in the Sheepscot, which receives a greater inflow of freshwater. Below 20 m mean salinities were similar in the three areas. The narrow range of mean salinities at the surface in the Damariscotta area was related to turbulence and mixing in the narrows above station 13. The Damariscotta estuary was not affected by the shallow gut leading to John's Bay, but water from the Sheepscot estuary flowed through the deeper Townsend Gut (6-15 m) reducing the mean salinity at station 7.

Average temperatures in the Sheepscot area indicated a relatively homogeneous distribution in the upper 10 m. A similar situation existed for highest temperatures. In the Boothbay area, mean and highest temperatures increased generally from the bottom upward because some of the shallow stations (6 and 9) were completely stratified throughout in the summer. The deeper stations of the Damariscotta area showed a relatively homogeneous layer from 20 m to the bottom. Lower temperatures reflected the lower winter air temperatures common to all of the areas.

At station 1 the seasonal progression of temperature and salinity was pronounced and was not obscured by advection of other water types or excessive turbulence, but represented seasonal events at other stations (Fig. 3). These were summer stratification, fall overturn, winter homogeneity and spring dilution. The estuary was coldest throughout its water column in late winter and coldest near the bottom during early spring. Salinity was highest in the winter, interrupted briefly by an increase in river discharge. With vernal warming and increased runoff salinity was lowered and the water column was stratified. By late spring to early summer this diluted water was mixed by the tides and removed from the estuary.

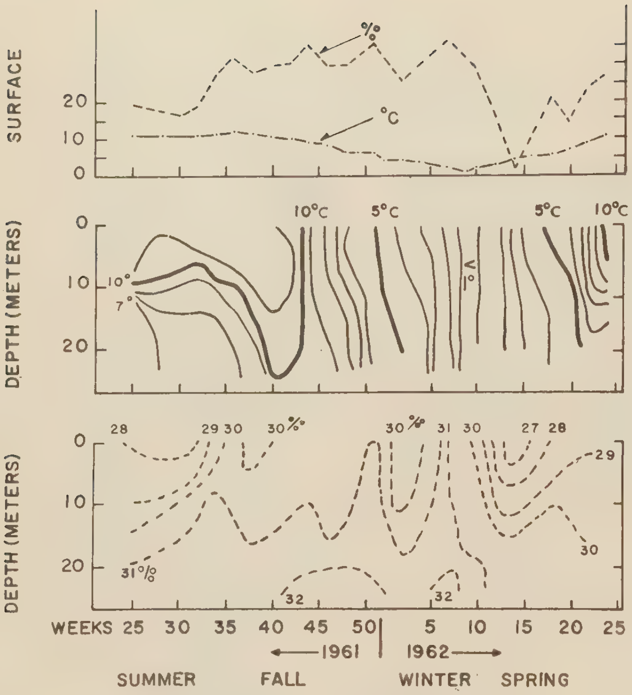


Fig. 3. Seasonal progressions of temperature and salinity at station 1 in the Sheepscot estuary. Original temperature measurements in degrees Fahrenheit and depths in feet.

During the year, either temperature or salinity controlled the density distribution. This is illustrated with selected shallow- and deep-water stations in Fig. 4. In April, the discharge of freshwater preceded thermal stratification and the steep density gradient at station 1 was more closely related to a change in salinity than temperature, although the gradient was accentuated by the colder bottom water. A steep gradient was not present during April at station 5 because the freshwater was well mixed through tidal action when it departed the estuary. Temperature was the dominant variable during the summer and fall, when the density of the entire water column was lowest. In the winter, the water column approached homogeneity except at stations in the Sheepscot area.

Displacement volumes of zooplankton obtained in meter net tows were not normally distributed and a median-quartile description (Snedecor, 1948) was used to summarize data from each of the 18 stations (Table 1).

TABLE 1. MEDIAN-QUARTILE DESCRIPTION OF PLANKTON VOLUMES

| | Range in ml | | |
|---|---|---|---|
| | Sheepscot | Boothbay | Damariscotta |
| Quartile 1 | 2.0 - 3.5 | 2.0 - 6.0 | 2.0 - 5.0 |
| Median | 4.0 - 6.5 | 4.0 - 8.0 | 4.0 - 9.5 |
| Quartile 3 | 5.75 - 12.0 | 11.75 - 18.75 | 11.00 - 27.0 |
| Extremes | < 1 - 70 | < 1 - 197 | < 1 - 341 |

The volumes in the first quartiles and medians overlap considerably between the three areas. This overlap is related, in part, to measuring small displacement volumes less than 5 ml. Very small volumes are present for all areas, but the third quartile, large volumes, showed a progressive increase from the Sheepscot to the Damariscotta. The three areas differed, as suggested above, in their average temperature and salinity distributions and in their resultant sigma-t values at the surface. In this regard, a positive correlation ($r = 0.562$, N-2 = 16, $P < .05$) was obtained between the third quartile of surface plankton volumes and sigma-t values at each station. Stations in the lower estuary of the Sheepscot River had the lower sigma-t values and lower plankton volumes while the Damariscotta area, particularly stations 17 and 18, more exposed to coastal waters, had the highest. The seasonal progression of zooplankton volumes from station 1 in the Sheepscot estuary was similar to those of the other stations and is shown in Fig. 5. The standing crop was high during late summer and early fall, low in the late fall and winter, high again in late winter and early spring, and low again during the late spring and early summer.

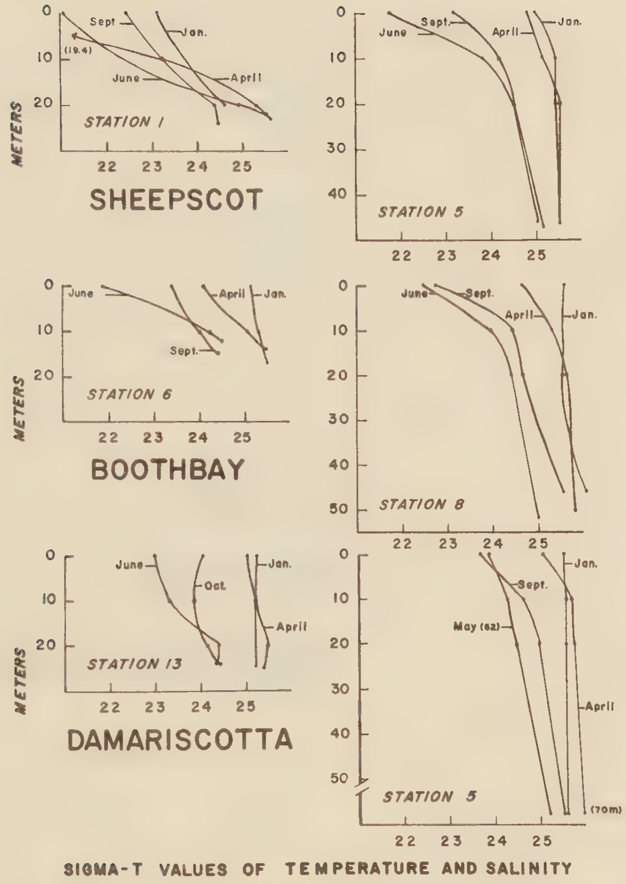


Fig. 4. Vertical distributions of density at selected shallow and deep water stations. See Fig. 1 for the location of numbered stations.

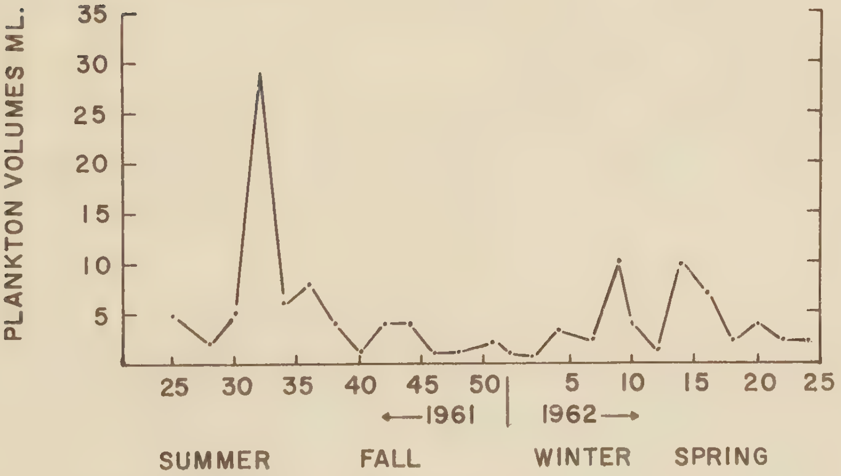


Fig. 5. Zooplankton volumes at station 1 in the lower Sheepscot estuary.

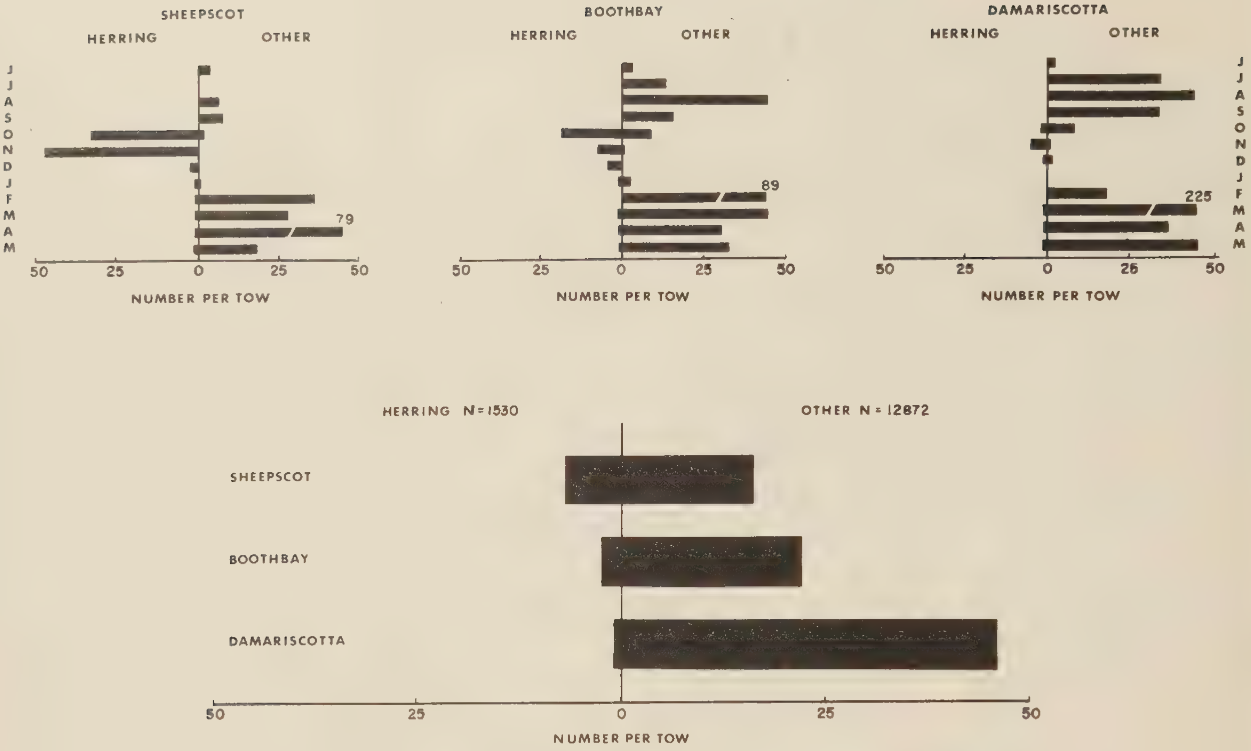


Fig. 6. Average number of herring and other fish larvae caught in surface tow

Larval distribution

Monthly meter-net catches of larval herring and other larval fishes had three notable features: 1) there were marked differences in the seasonal distributions of larvae, 2) the differences in areal distribution were equally marked, 3) the seasonal and areal distribution of herring larvae was inverse to that of other larvae (Fig. 6).

Herring larvae were first captured in October and were relatively abundant. Catches were largest in the Sheepscot and smallest in the Damariscotta area. Their numbers increased in the Sheepscot and Damariscotta areas during November but decreased in the Boothbay area. By December, there was a sharp drop in all areas and catches remained at a low level. During February, herring larvae were not captured in the Boothbay area, nor in January and February in the Damariscotta area. The average number per tow decreased from the Sheepscot to the Damariscotta area.

The number of larvae captured in vertical meter-net tows was small, 50 during October and November, a period of relative abundance at the surface. No particular pattern of areal distribution or relation to surface catches was discernible. Possibly the distances towed, 14-67 m, were too short and the amounts of water strained, 12-52 $m^3$, too little to register any distinct pattern of distribution. Surface samples strained 1,550 $m^3$ and were towed for 830 m. Otter trawling was largely unsuccessful in capturing the larger larval herring in the spring and summer. When larvae were captured, they were entangled in the leading meshes of the trawl with only a few reaching the cod end liner.

Very small herring larvae (< 9 mm standard length) were present in October and November. (Fig. 7). Recruitment of these small larvae ended in December when both the range and mean length increased considerably. From October through May there was a consistent increase in length. In the fall to early winter months, smaller larvae were captured in the Sheepscot than in the other areas. Most of the larvae (1,530) were captured in the fall with a surface meter-net tow; the remainder (188) were captured during the spring when otter trawling.

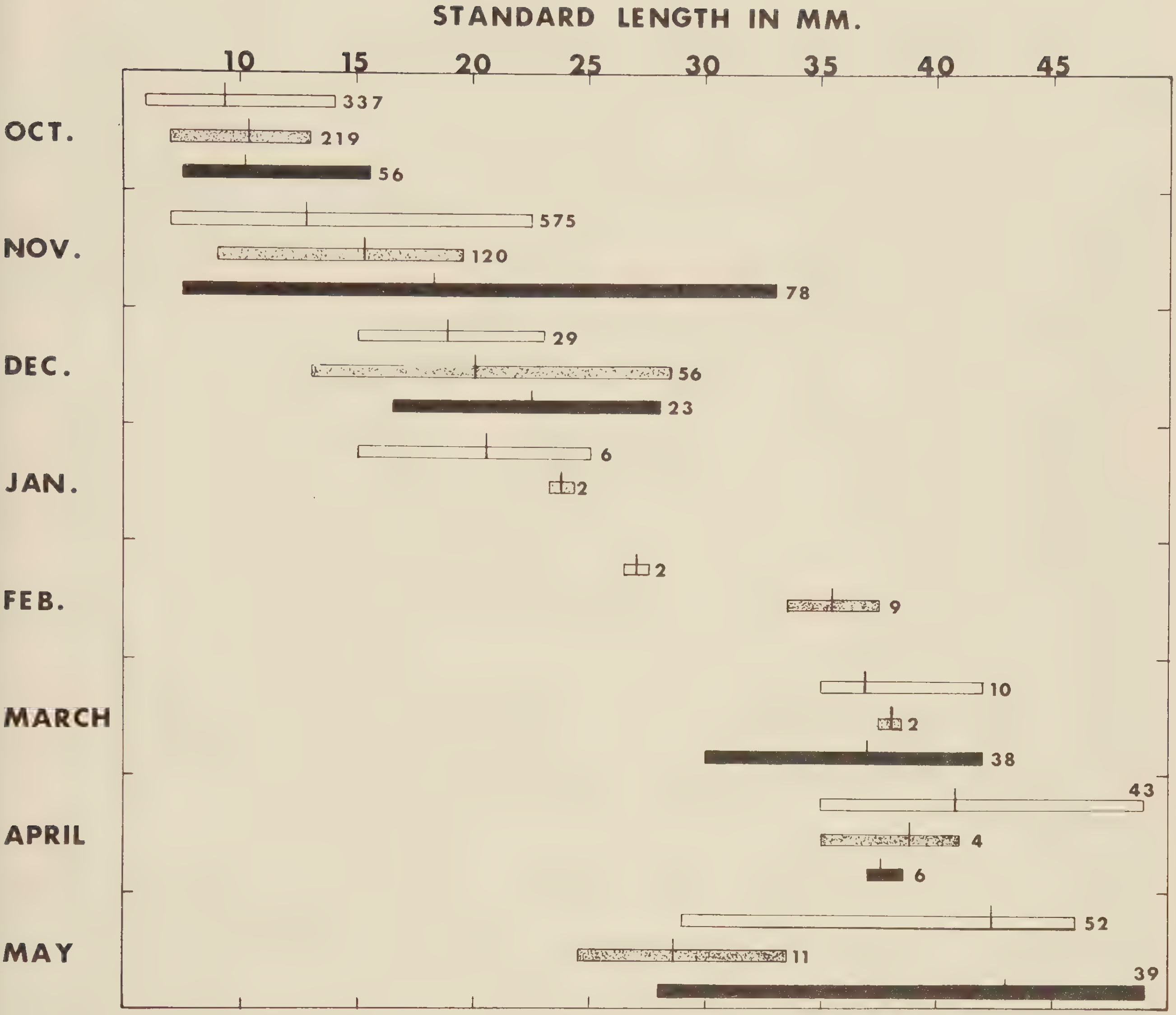


Fig. 7. Monthly average length (vertical line) and range (bars) of larval herring captured in meter net and otter trawl tows. The light, stipled, and dark bars represent the Sheepscot, Boothbay, and Damariscotta areas, respectively. The number of fish measured is given to the reader's right for each bar.

In contrast to the fall distribution of herring, larvae of other fishes were caught in largest numbers during the spring and summer. Monthly catches of other larvae were generally highest in the Damariscotta area and lowest in the Sheepscot; an extensive period of low catches occurred between October and February. The more abundant species during the spring months were: *Ammodytes americanus*, *Myxocephalus scorpius*, and *Pholis gunnellus*; and during the summer months: *Ulvaria subbifurcata*, *Enchelyopus cimbrius*, and *Cyclopterus lumpus*. The numbers, and mean standard lengths of larvae other than herring are given in Table 2. Unlike herring larvae, some species showed no consistent increase in mean length.

The seasonal occurrence of other juvenile and adult fishes in the otter trawl catches is shown in Fig. 8. Although there is some variation from month to month, peaks in relative abundance appeared in the fall and spring, with lows in the summer and winter.

TABLE 2. NUMBER AND MEAN LENGTH OF FISH LARVAE, OTHER THAN HERRING, CAPTURED IN THE SHEEPSCOT-BOOTHBAY-DAMARISCOTTA REGION OF MAINE, 1961-62. (EELS, *ANGUILLA ROSTRATA*, WERE IN THE ELVER DEVELOPMENTAL STAGE.)

| | JUNE | JULY | AUG. | SEPT. | OCT. | NOV. | DEC. | JAN. | FEB. | MAR. | APR. | MAY |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Cyclopterus lumpus | 16/6.7 | 24/4.7 | 47/5.3 | 48/6.3 | 12/10.2 | 3/9.0 | | 1/5.9 | 62/6.3 | 179/7.2 | 151/11.6 | 75/7.5 |
| Ulvaria subbifurcata | 18/7.9 | 826/7.3 | 861/8.7 | 378/8.8 | 36/7.9 | 4/11.8 | | | | | 6/7.0 | 1183/7.1 |
| Gadus morhua | 4/28.3 | | | | | | | | | | | |
| Urophycis chuss | 1/5.0 | 1/68.5 | 8/3.2 | 16/6.2 | 19/3.5 | 2/9.4 | | | | | | |
| Gasterosteus aculeatus | 2/19.5 | 1/18.5 | 1/34.0 | | | 1/27.0 | | | | | | 1/32.0 |
| Enchelyopus cimbrius | | 1/42.5 | 53/4.4 | 143/4.2 | 208/3.5 | 1/23.5 | | | | | | |
| Syngnathus fuscus | | | 9/16.7 | 1/18.5 | | | | | | | | |
| Scophthalmus aquosus | | | 9/3.1 | 5/3.9 | 2/3.5 | | | | | | | |
| Merluccius bilinearis | | | 29/3.2 | 3/3.2 | | | | | | | | |
| Glyptocephalus cynoglossus | | | 4/5.2 | 1/5.5 | 5/6.7 | | | | | | | |
| Sebastes marinus | | | | 5/38.0 | | | | | | | | |
| Tautogolabrus adspersus | | | 52/4.4 | 38/4.6 | 9/5.3 | | | | | | | |
| Scomber species | | | 5/5.3 | | | | | | | | | |
| Pollachius virens | | | | | | | 1/143.5 | | | | | |
| Pholis gunnellus | | | | | | | | 19/11.9 | 426/10.2 | 4150/13.4 | 775/12.6 | 62/13.1 |
| Gadus or Pollachius species | | | | | | | | | 9/24.9 | 17/22.8 | 39/25.7 | 95/25.1 |
| Lumpenus lumpretaeformis | | | | | | | | 6/17.8 | 16/18.2 | 16/18.6 | 6/18.8 | 15/18.4 |
| Myoxocephalus scorpius | | | | | | | | 30/7.5 | 299/7.6 | 942/9.9 | 334/12.2 | 92/15.1 |
| Cryptacanthodes maculatus | | | | | | | | | 23/18.9 | 151/18.7 | 99/20.1 | 6/30.0 |
| Anarhichas lupus | | | | | | | | | 1/5.0 | 1/8.5 | | |
| Ammodytes americanus | | | | | | | | 1/6.5 | 2/5.4 | 115/5.4 | 200/18.3 | 196/21.2 |
| Anguilla rostrata | | | | | | | | | 1/55.0 | 3/56.8 | 9/57.6 | 3/59.3 |
| Aspidophoroides monopterygius | | | | | | | | | | | 5/9.6 | 30/12.2 |
| Myoxocephalus octodecemspinosus | | | | | | | | | | | 51/6.4 | 32/6.8 |
| Melanogrammus aeglefinus | | | | | | | | | | | 6/5.9 | |
| Limanda ferruginea | | | | | | | | | | | | 7/5.2 |

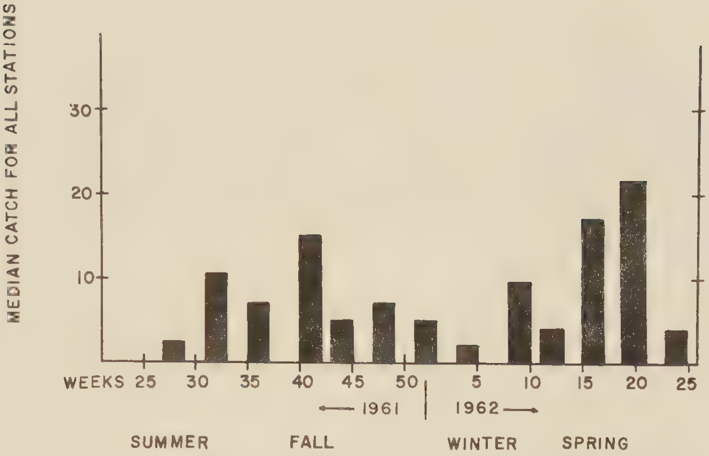


Fig. 8. Seasonal variation in the number (median) of fishes other than herring captured by 20-min otter trawl tows.

## DISCUSSION

### Distribution of larval herring

In the Gulf of Maine, the largest spawning grounds are found on the northern edge of Georges Bank and off the Nova Scotia coast (Tibbo *et al.*, 1958). Non-tidal drift suggested that some newly hatched larvae, determined by size (< 9 mm), were carried northward from Georges Bank to the Nova Scotia coast, but the majority were carried southward. Few inshore spawnings have been reported and confirmed and there is no evidence of large spawning grounds along the Maine coast.

The presence of very small herring larvae in the Sheepscot-Boothbay-Damariscotta region suggested that their source was local. Recent catches of herring with gonads in a running state and catches of yolk-sac larvae were recorded from the vicinity of station 11 during the fall of 1963. Regardless of their source, larvae in their early planktonic stage would have obtained some assistance from currents to introduce or maintain themselves in the bays and estuaries. This assistance could be in the form of both non-tidal and tidal currents. The presence of the greatest numbers of larvae in the Sheepscot area suggested that transport by non-tidal currents was important. The Sheepscot estuary is influenced by freshwater discharge while the Boothbay area has no major streams entering it. The Damariscotta area has a smaller stream entering it and its effects are masked by considerable turbulence. In the Sheepscot estuary the discharge of river water was lowest in the fall and vertical sigma-t gradients were largely a function of thermal stratification rather than changes in salinity. Vertical density gradients in the Sheepscot were not steep and a two layered estuary would be poorly developed for conveying larvae inward along the bottom. In contrast, a lateral flow would be accentuated by water of lower salinity entering from the Kennebec River. This water enters the Sheepscot from Goose Rock Passage and flows southward along the western side of the estuary. Tidal currents could transport larvae in water eddying behind promontories (Stommel, 1953) and other rugged features common to the region. Stranding of larvae in an eddy would make it possible for advancement upstream on the next flood tide.

The distribution of other larvae complements that of herring. Many of these larvae were obtained in a planktonic stage and presumably were susceptible to transport by currents, particularly in the spring when river discharge was at its height. Their distribution could be associated with their behavioral attributes or to the location of spawning grounds; little is known locally of either aspect of their biology.

### Avoidance of net and migration

Catches of herring larvae decreased with an increase in larval size. Bridger (1956) found that more clupeid larvae were taken with a 1-m silk tow net and other nets at night. He suggested that the lower catches of larvae by daylight were related to avoidance of the net by larger larvae and discounted the possible effects of shoaling, dispersal, and congregation near the bottom by day. Colton (1961) found that escapement and diurnal migrations influenced the catches of larval herring in the Gulf of Maine. His tows were limited to 10 m and were made with a 1-m plankton net. The seasonal abundance of herring larvae in this study was similar to that obtained in the Gulf of Maine and the Bay of Fundy (Tibbo *et al.*, 1958; Colton *et al.*, 1961). That is, 1) larvae were captured in greatest numbers in the fall, 2) catches were subsequently small during the winter months, 3) recruitment of newly hatched larvae was completed by the winter months. While the sharp drop in larval catches was probably related to escapement as indicated by Colton *et al.* (1961) the movement of fish from the vicinity of the sampling stations was also suspect. Recently, explorations were made upstream of station 1 in the Sheepscot, during the winter and early spring, and a concentration of larvae was found. Their size (30 - 35 mm) agreed with the growth expected since the fall. Apparently, herring larvae overwinter in the Sheepscot. To test this hypothesis this upstream area is being sampled routinely with high speed sampling gear and samples are taken from the surface to the bottom.

## CONCLUSIONS

This study provided the first evidence that herring larvae utilize the estuarine environment along the Maine coast. The distribution of herring larvae differed in the three adjacent embayments studied. More herring were captured in the Sheepscot area than the Boothbay and Damariscotta areas. Differences in the seasonal distribution of herring larvae were marked, with the greatest abundance occurring in the fall. The seasonal and areal distribution of other fish larvae was inverse to that of herring larvae. Eastward from the Sheepscot to the Boothbay and Damariscotta areas average salinities, surface temperatures, and surface standing crops of zooplankton increased.

## REFERENCES

BHATTACHARYYA, R.N. 1957. The food and feeding habits of larval and post larval herring in the Northern Sea. *Mar. Res.*, no. 3, 16 p.

BRIDGER, J.P. 1956. On day and night variation in catches of fish larvae. *J. Cons.*, 22 (1): 42-51.

COLTON, J.B., Jr., K.A. HONEY and R.F. TEMPLE. 1961. The effectiveness of sampling methods to study the distribution of larval herring in the Gulf of Maine. *J. Cons.*, 26 (2): 180-190.

HOPKINS, THOMAS L. 1963. The variation in the catch of plankton nets in a system of estuaries. *J. Mar. Res.*, 21 (1): 39-47.

SMAYDA, THEODORE J. 1957. Phytoplankton studies in lower Narragansett Bay. *J. Limnol., Oceanogr.*, 11 (4): 342-359.

SNEDECOR, GEORGE W. 1948. *Statistical Methods.* Fourth Edition, Ames, Iowa, Iowa State College Press, 485 p.

STICKNEY, ALDEN P. 1959. Ecology of the Sheepscot River estuary. *Spec. sci. Rep. U.S. Fish Wildl. Serv. - Fish.*, No. 309, p. 1-21.

STOMMEL, HENRY. 1953. The role of density currents in estuaries. *Proceedings Minnesota International Hydraulics Convention*, 1-5 September, 1953. (Contribution no. 655, Woods Hole Oceanographic Institution, p. 305-312).

TIBBO, S.N., J.E. HENRI LEGARE, LESLIE W. SCATTERGOOD and R.F. TEMPLE. 1958. On the occurrence and distribution of larval herring (*Clupea harengus* L.) in the Bay of Fundy and the Gulf of Maine. *J. Fish. Res. Bd. Canada*, 15 (6): 1451-1469.

U.S. GEOLOGICAL SURVEY. 1962. Surface water records of Maine 1961. District Engineer, Surface Water Branch, *U.S. Geological Survey*, Augusta, Maine, 70 p.

1962*a*. Sheepscot River discharge, October 1961 to September 1962 (Provisional). District Engineer, Surface Water Branch, *U.S. Geological Survey*, Augusta, Maine, Mimeographed, 1 p.

# A New Depressor Design for High Speed Samplers

by

Joseph J. Graham and George B. Vaughan

(Abstract)

The Boothbay depressor design was developed to tow sampling devices throughout the water column at high speed (4-1/2 - 6-1/2 knots). The depressor is a pivoting blade of sufficient area to maintain the desired depth at which a sampling device travels. For bottom contact, pivoted feet extend below the blade and connect to it by arms. On contact the blade is diverted from a depressing to a surfacing angle preventing it from digging into the bottom. Data are given concerning stability in midwater and on bottom. The application of the depressor design to high speed samplers is discussed. Adaptations of the design to two trawls and the Gulf III sampler are discussed.

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# A Thermal-Marking Technique for Juvenile Salmonids

ALAN B. GROVES AND ANTHONY J. NOVOTNY

# A Thermal-Marking Technique for Juvenile Salmonids

## INTRODUCTION

Work with juvenile salmonids often calls for short-term marking techniques by which individual fish or groups of fish may be identified for varying periods. Such recognition can be provided by various familiar means such as fin removal, attachment of markers or tags, tattooing, or perhaps whole-body staining.

Although the above methods may each serve in specific applications, a simple, quickly learned technique is needed which will permit the rapid use of a variety of visible surface marks such as letters, numbers, or symbols, by which *individual* fingerlings may be recognized easily over intervals of weeks or months. The purpose of this report is to describe a marking system which appears to meet such needs. The method consists of marking juvenile salmonids by topical application of mild heat to dorsal skin surfaces.

Use of heat to mark or brand small fish has been attempted previously. In such instances the levels of applied heat have been relatively high. Buss (unpublished) marked young brook trout with a wood-burning pencil. He reported that some brands remained visible after 21 months and one after 4 years. Johnson and Fields (1959) tried to mark fingerling steelhead by applying to the skin surface a nichrome wire electrically heated to white heat. According to the authors, this caused injuries which penetrated the skin. Though these were readily visible, they were slow in healing. After 5 months no distinguishable marks or scars were left. Similarly, white-hot wire was used by Watson (1961) to mark young sea herring. He reported that scars were discernible after 7 months, but differences between marks were evident only during the first several days.

To mark fingerling salmon we explored the use of a small electrical soldering iron with the heat tips shaped into various patterns. The trials were not satisfactory. Marks could not be produced consistently at heat levels other than those which caused lesions penetrating through the skin into the underlying musculature. Though the resultant injuries appeared as prominent dark gray marks, they bore no resemblance to the patterns of the heat tips and left no visible traces after a 3-month healing period.

These results indicated that substantially lower applied heat levels would be necessary to avert excessive damage to the contact areas. Such attempts were made, but no marks were produced. This lack of success may have been due to the limited thermal capacities of the marking tools.

Thereupon, new applicators were designed to enhance such characteristics as heat storage and conductance. To employ a level of heat considerably lower than that applied previously, boiling water was used to heat the applicators. This heat source and the specially designed tools have made practicable the effective marking technique described herein.

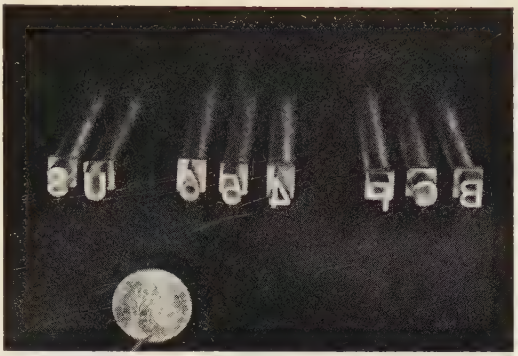

FIGURE 1.—Closeup of the solid silver tips on the marking tools. Ten cent piece shows size relationship.

## MATERIALS AND METHODS

The marking tools are made from metals having superior thermal conductance properties. A pencil-sized piece of copper tubing forms the handle. The marking tip is silver, smoothly polished to facilitate heat transfer. This is cut according to the desired pattern from a quarter-inch-thick plate, to form a flat surfaced figure which is mounted and soldered in reverse (Figure 1) onto a matching piece of one-eighth-inch-thick silver. This in turn is soldered to the end of the copper tube. This physical continuity maintains a relatively uniform heat flow from the handle to the marking surface when applied to a fish. The handle is insulated by polyvinyl tubing which covers the copper except for the first 2 inches from the marking tip. Only the tip (plus 1 inch of the uninsulated portion) was immersed in the heating water. Currently the tools are produced by a manufacturing jeweler at a unit cost of about eight dollars.

Fish used in the tests were juvenile sockeye salmon (*Oncorhynchus nerka*), rainbow trout (*Salmo gairdneri*), fingerling spring chinook salmon (*O. tshawytscha*), and coho salmon (*O. kisutch*).

Fish to be marked were anesthetized and held in aerated solutions of M.S. 222. The actual marking procedure was simple. After the

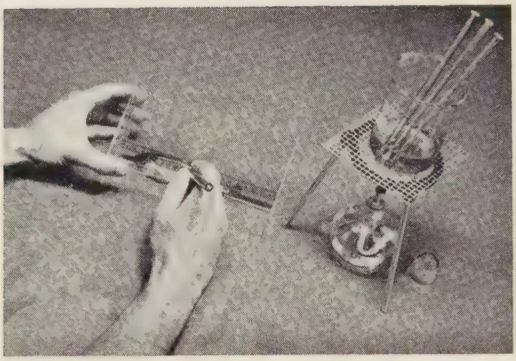

FIGURE 2.—Applying a thermal mark (dorsolateral) to a chinook salmon fingerling. Engraved plastic disc at top of copper handle identifies marking tool and insures proper alignment during marking. Photograph depicts the minimal equipment needed for thermal marking—marking tools, water, and a heat source.

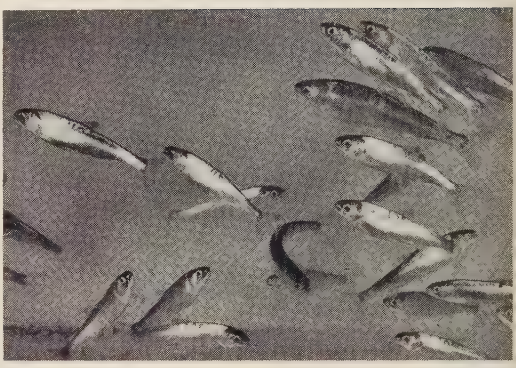

FIGURE 3.—Year-old sockeye salmon fingerlings about 3½ months after marking. Differences in the apparent visibility of the marks are due to the variations in position of the fish with respect to the incident light.

fish was taken from the anesthetic, the marking tool was removed from the heating water, shaken to remove any drops, and applied to the skin surface between the lateral line and dorsal fin. A light, positive, even contact was maintained for about one and one-half seconds (Figure 2). The fish was returned to water and the marker placed back into the heating container. No more than one application with the same tool was made without reheating. The relative rapidity of the procedure permitted holding the fish out of water during the application of multiple marks. In such instances, the temperatures of the anesthetic solutions were held down to around 45 F to help offset any possible increased handling stress.

Clear marks depended mostly on steadiness of the applicator during contact. Occasional blurring resulted from uneven contact, probably due to small amounts of mucus adhering to the marker. In most instances, however, the boiling water kept the figures clean. Immediately following application, little indication of marking was evident—other than a faint whitish outline of the mark. Minutes after the fish revived from the anesthetic, the mark usually appeared prominently dark against the normal pigmentation.

## RESULTS AND DISCUSSION

In the laboratory the method has been used to place a variety of persistent marks (Figure 3) on fingerling salmonids ranging from 85 to 160 mm in length. Six months after marking, juvenile sockeye displayed the original figures with little loss of clarity. Similar results were obtained with spring chinook fingerlings.

Two hundred forty-four juvenile rainbow trout were individually marked with serially consecutive Arabic numerals. One month later any of these fish could be identified by its number. After 2 months, the numbers were still evident on all fish, but apparent local differentials in skin growth had distorted some numerals. Ten months later the fish had grown from about 100 mm to over 200 mm in length. All fish still had visible marks. These figures were two to three times their original size, but some were indistinct, and it was not possible to re-identify all individuals. Numbers on some trout were outlined by a patterned alignment of dark pigment spots. A similar heat marking effect on rainbow was noted by Buss (1961).

Marking caused no mortalities in these tests. Overall comparisons between marked fish and control groups indicated no differences in general behavior responses or activity.

In the field, the technique has been used successfully to mark over 23,000 juvenile chinook salmon and rainbow trout migrating downstream in the Snake River. These ranged in length from 90 mm to 240 mm. Marked fish were identified easily upon recovery after varying intervals up to 45 days.

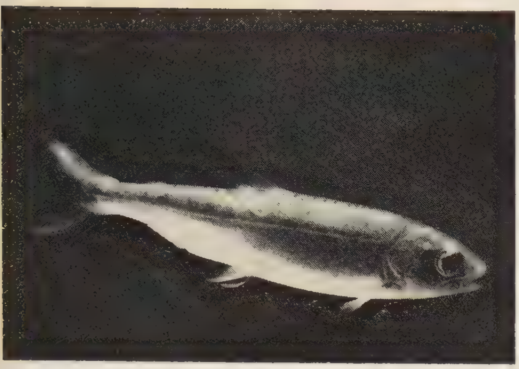

FIGURE 4.—Six-month-old mark on one of the fish shown in Figure 3. Although faded, the mark is still visible.

The applied heat evidently alters normal pigmentation at the contact site. Initial mark visibility appears due to localized disruption of chromatophores and dispersion of dark pigments. This aspect usually lasts for a number of days. Later, the silvery pigment guanine seemingly disappears from the contact area, and the resultant reflective contrast gives a high accent to the mark. In laboratory tests this quality has persisted for several months. With chinook and sockeye salmon, as the guanine reappears in the site, the distribution of darker pigment usually is less—so that the mark appears lighter than the surrounding area (Figure 4). Except with rainbow trout, as noted, pigment differences in the mark area fade gradually within a year. Upon close examination, however, local differences in reflection of incident light can be seen which still may be distinguished as the original mark. One sockeye and one silver salmon in the laboratory displayed such marks 18 months after application.

Results so far indicate that the condition of the fish is related to marking success. Sound, actively feeding, growing fingerlings usually can be marked as described, but if the fish are less than healthy, the probability of consistent mark production appears diminished. Limitations in fish size for which the technique is effective have not yet been determined. Though the observed pigment changes may be related to age factors, they may well be the results of heat alone. Therefore, application time or applicator size should be considered in relation to size of the fish. Also to be determined are possibilities that more permanent features of the skin, such as scales, may be influenced by the heat application.

Based on the testing to date, the method shows considerable promise as a simple system for placing an impressive variety of short-term marks on fingerling salmonids. It may be of help in a number of laboratory or field applications.

## LITERATURE CITED

BUSS, KEEN. 1961. There's more than one way to leave a mark on life. Pennsylvania Angler 30(10): 2–5.

JOHNSON, DONALD E., AND PAUL E. FIELDS. 1959. The effectiveness of an electric hot-wire branding technique for marking steelhead fingerling trout. College of Fisheries, University of Washington, Technical Report No. 47, 4 p.

WATSON, JOHN E. 1961. The branding of sea herring as a short term mark. Prog. Fish-Cult. 23: 105.

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# UPTAKE AND RETENTION OF CESIUM 137 AND ZINC 65 BY SEAWEEDS

BY JOHN GUTKNECHT

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# UPTAKE AND RETENTION OF CESIUM 137 AND ZINC 65 BY SEAWEEDS

by John Gutknecht

# UPTAKE AND RETENTION OF CESIUM 137 AND ZINC 65 BY SEAWEEDS[1]

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## ABSTRACT

Uptake and retention of $Cs^{137}$ and $Zn^{65}$ by seaweeds were observed under various environmental conditions. Concentration factors and biological half-lives varied widely among species, $Zn^{65}$ showing generally higher levels of uptake and retention. No significant relationship between growth rate and either concentration factor or biological half-life was found among the species tested.

Both uptake and loss of $Cs^{137}$ were stimulated by light, but some $Cs^{137}$ movements occurred in the dark. Both exogenous substrate (glutamate) and previous exposure to light stimulated $Cs^{137}$ uptake in the dark. Exposure to nitrogen in the dark inhibited both influx and efflux of $Cs^{137}$. Neither darkness nor anoxia caused appreciable net loss of absorbed $Cs^{137}$. $Cs^{137}$ was not extensively adsorbed by cell walls or killed tissue. Influx and efflux of Cs were proportional, respectively, to the external and internal Cs concentrations. Intracellular Cs appears to be largely ionic, with Cs movements being closely related to metabolism.

$Zn^{65}$ was highly concentrated by living and killed algae and by cell walls. Light had a variable effect on $Zn^{65}$ movements. Zinc uptake at different external Zn concentrations agreed with the Freundlich adsorption equation. Adsorption exchange appears to be an important mechanism of Zn movements in seaweeds.

## INTRODUCTION

The increasing occurrence of $Cs^{137}$ and $Zn^{65}$ in coastal waters has stimulated recent studies on the uptake and retention of these radionuclides by both aquatic biota and sediments (for reviews, *see* Davis 1963 and Rice 1963*a*). Seaweeds, although they may be the principal primary producers of the littoral zone (Blinks 1955), have been less studied than phytoplankton with regard to environmental contamination. However, seaweeds are often involved in food chains leading to man, since they are harvested commercially for food, feed, and fertilizer (*see* Davy de Virville and Feldmann 1964). The importance of seaweeds in radioactive waste disposal was demonstrated at the Windscale Atomic Works, England, where the activity absorbed by edible *Porphyra* limited the permissible rate of release (Dunster 1958).

The uptake of both $Cs^{134}$ and $Zn^{65}$ has been reported to be related to photosynthesis in seaweeds, thus suggesting a possible use for these tracers in studies of energy flow. Scott (1954) found that accumulation of $Cs^{134}$ by *Rhodymenia* was dependent upon light and $CO_2$, and he concluded that there was an intimate connection between the mechanisms of cesium absorption and photosynthesis. Bachmann and Odum (1960) also reported a relationship between productivity and $Zn^{65}$ uptake by marine algae, but their method has been criticized (Gutknecht 1961).

Zinc is an essential nutrient for algae (*see* Wiessner 1962), as well as for higher plants and animals (*see* Vallee 1962 and Nason and McElroy 1963). Cesium is apparently a nonessential trace element, but it is accumulated by most cells in a manner qualitatively similar to potassium (*see* Relman 1956). Thus, the biological uptake of $Zn^{65}$ and $Cs^{137}$ is of interest from a physiological, as well as from an ecological and health physics, point of view.

This paper is a report on the uptake and retention of $Zn^{65}$ and $Cs^{137}$ by some seaweeds from the Woods Hole, Massachu-

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setts, and Beaufort, North Carolina, areas. Terminology will conform in general to that used by Laties (1959) in describing various types of ion uptake and loss by plant tissues.

Thanks are due to Dr. T. R. Rice, Director, and to the staff of the Bureau of Commercial Fisheries Radiobiological Laboratory for helpful discussions and critical reading of the manuscript. The technical assistance of James N. Willis is gratefully acknowledged. Facilities for part of this work were provided by the Marine Biological Laboratory, Woods Hole, Massachusetts.

## METHODS

Algae were collected from the Woods Hole and Beaufort harbors and kept in Plexiglas tanks of continuously aerated seawater under natural illumination (north window exposure). Small portions of the plants were exposed to $Cs^{137}$ and $Zn^{65}$ in 1-liter flasks of aerated seawater medium. Periodically, the plants were removed from the flasks and their radioactivity and fresh weight determined after blotting with absorbent tissue.

The medium was Millipore®[3]-filtered (Type AA) seawater to which 20 $\mu$M each of $NaNO_3$ and $NaH_2PO_4$/liter were added. The medium was replaced every day so that significant depletion of the tracers did not occur. All solutions were buffered at $p$H 8.0 with Tris (hydroxymethyl) amino methane. Experiments were carried out either in the dark or at a constant illumination of 7,500 lux provided by six "daylight" fluorescent tubes. The temperature was 21 ± 2C.

$Cs^{137}$ and $Zn^{65}$ uptake by killed algae (killed by cold 50% ethanol or heat) and by isolated cell walls of *Ulva lactuca* also was observed. *Ulva* thalli are sometimes found to have transparent borders in which every cell has liberated gametes or zoospores following a repeated bipartition of the entire protoplast (Smith 1955). Microscopic examination reveals two layers of empty cells that are relatively free of debris and microorganisms. Thus, an estimate of $Zn^{65}$ or $Cs^{137}$ uptake by cell wall vs. living cell could be obtained by comparing equal areas of empty-cell material and living tissue from adjacent sites on the same thallus.

Total zinc was determined as follows: Samples were digested with concentrated $HNO_3$, taken to dryness, and placed in a muffle furnace overnight at 475C. They were then taken up in 2 N HCl, and the zinc was separated by ion exchange, using the method of Kraus and Moore (1953). The zinc-containing effluent was analyzed by a modification of the dithizone technique of Vallee and Gibson (1948). Results were corrected for radiochemical yield.

Radioactivity was measured with either a conventional well-type scintillation detector for integral counting or a single-channel analyzer for differential counting of $Zn^{65}$-$Cs^{137}$ or $Cs^{137}$-$Cs^{134}$ mixtures. In most experiments, the activity of the medium was 4 $\mu$c $Zn^{65}$ and 20 $\mu$c $Cs^{137}$/liter. Unless otherwise indicated, carrier-free tracers were used, so that the natural concentration of zinc and cesium was not appreciably increased. Since chemical analyses for total cesium were not feasible in this study, net cesium movements were deduced from $Cs^{137}$ or $Cs^{134}$ fluxes. The natural cesium content of seawater was assumed to be 0.5 ± 0.05 $\mu$g/liter (Smales and Salmon 1955).

## RESULTS

### *Concentration factor and biological half-life of $Zn^{65}$ and $Cs^{137}$ in seaweeds*

Algae were exposed to $Zn^{65}$ and $Cs^{137}$ in the light as described above. When they reached an apparent steady state with the radioactivity of the medium (5–40 days, depending on the species), they were transferred to nonradioactive seawater, and the loss of activity was observed. The biological half-life ($T_{b\frac{1}{2}}$) of each isotope was estimated by the method of Odum and Golley (1963). Upon completion of the

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[3] Registered trademark, Millipore Filter Corporation, Bedford, Massachusetts.

TABLE 1. *Uptake and retention of* $Zn^{65}$ *and* $Cs^{137}$, *total Zn, and growth rate of seaweeds. Uptake expressed as concentration factor* $\left(\frac{\text{count min}^{-1}\text{ g}^{-1}\text{ fresh wt}}{\text{count min}^{-1}\text{ ml}^{-1}\text{ medium}}\right)$ *(CF), and retention expressed as biological half-life* ($T_{b½}$)*

| Species | $Cs^{137}$ |  | $Zn^{65}$ |  | Total zinc (mg/kg) |  | Growth rate (% increase fresh wt/day) |
|---|---|---|---|---|---|---|---|
|  | CF | $T_{b½}$ (days) | CF | $T_{b½}$ (days) | Fresh wt | Dry wt |  |
| *Ulva lactuca* | 7 | 5 | 290 | 4 | 23.8 | 158 | 15.0 |
| *Codium decorticatum* | 4 | 15 | 30 | 7 | 0.96 | 17.0 | 7.9 |
| *Fucus vesiculosus* | 30 | 8 | 3,300 | 100 | 124 | 472 | 3.0 |
| *Dictyota dichotoma* | 10 | — | 280 | 14 | 5.70 | 35.0 | 8.2 |
| *Porphyra umbilicalis* | 5 | 3 | 255 | 7 | — | — | 7.5 |
| *Chondrus crispus* | 30 | 2 | — | — | — | — | 1.8 |
| *Gracilaria foliifera* | 25 | 12 | 210 | 60 | 5.83 | 37.7 | 5.3 |
| *Agardhiella tenera* | 6 | 21 | 395 | 70 | 9.78 | 91.4 | 5.2 |
| *Hypnea musciformis* | 11 | — | 150 | — | 3.54 | 23.2 | 5.5 |

* Conditions: constant illumination (7,500 lux), *p*H 8.0, 21C. Each value is the average of samples from at least 4 plants.

experiment, the algae and media were analyzed for total zinc. Results are shown in Table 1.

$Zn^{65}$ uptake among species varied by about two orders of magnitude. *Fucus* showed by far the highest concentration factor (CF), 3,300, while *Codium* showed the lowest, 30. Concentration factors for $Cs^{137}$ were less variable, ranging from 30 in *Fucus* to 4 for *Codium.* The values for $Cs^{137}$ are slightly lower than those reported by Smales and Salmon (1955), who used radioactivation analysis for total cesium in seaweeds. Biological half-lives ranged from >100 days for $Zn^{65}$ in *Fucus* to 2 days for $Cs^{137}$ in *Chondrus.* There was no significant correlation between net production, that is, growth rate, and the CF or $T_{b½}$ of $Cs^{137}$ or $Zn^{65}$ in these species.

Total zinc concentrations ranged from 124 mg/kg fresh wt for *Fucus* to 0.96 mg/kg in *Codium.* The zinc content of the medium was 49 μg/liter. The final specific activity of $Zn^{65}$ in the medium was approximately the same as the specific activity of $Zn^{65}$ in the algae, the CF values for total zinc being from 0.41 to 1.7 times those for $Zn^{65}$.

### *Nonmetabolic uptake of* $Cs^{137}$ *and* $Zn^{65}$

The uptake of an element by killed cells is sometimes used to estimate the amount of nonmetabolic absorption in living cells (Kuenzler and Ketchum 1962; Rice 1956; and others). This method gave low CF values of 1–2 for $Cs^{137}$ in killed tissues of all species and cell walls of *Ulva.* Nonmetabolic uptake by living tissue also may be estimated by the size of the "absorption shoulder," that is, the intercept of the linear phase of the uptake-time curve (Laties 1959). This method would be expected to yield values somewhat lower than those obtained with killed tissue, since it is mainly a measure of uptake by extracellular components. Concentration factors for $Cs^{137}$ obtained by this method ranged from 0.4 to 0.5. Furthermore, seaweeds which had been exposed to $Cs^{137}$ for up to 35 days released more than 90% of their activity when killed and kept for several hours in the same radioactive medium. Thus, neither physical adsorption, adsorption exchange, nor nonexchangeable binding can account for much of the $Cs^{137}$ taken up by these algae.

In contrast, considerable nonmetabolic uptake of $Cs^{137}$ by both living and killed freshwater plants has been reported (Krumholz 1954; Williams 1960; and others). However, competition for potential $Cs^{137}$ adsorption sites in freshwater material is undoubtedly less than in seawater. For example, it was found that killed seaweeds took up 5–10 times more $Cs^{137}$ in radioactive tap

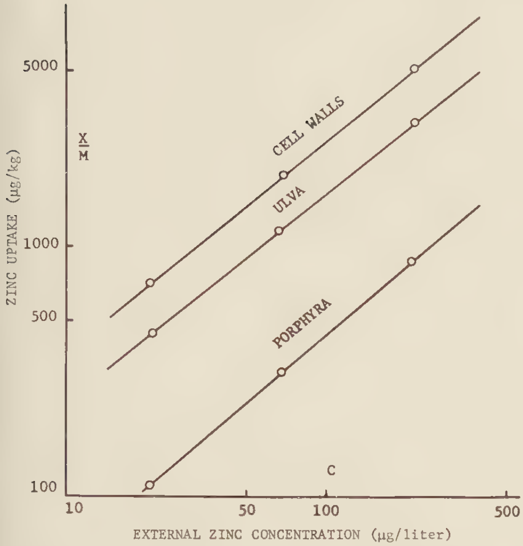

FIG. 1. Effect of external Zn concentration on uptake by *Porphyra*, *Ulva*, and cell walls of *Ulva*. Time of exposure: 24 hr in the light. Each point is the average of 4–6 discs of tissue.

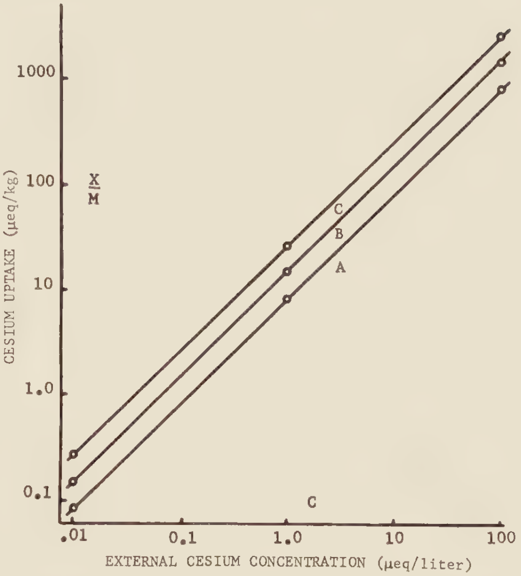

FIG. 2. Effect of external Cs concentration on Cs uptake by *Gracilaria* after 1 day (A), 2 days (B), 9 days (C) in the light. Each point is the average of 6–12 branches.

water at *p*H 8.0 than in a seawater medium of the same activity. Similarly, the sorption of $Cs^{137}$ by estuarine sediments has been reported to be inversely related to salinity (Duke 1963).

The empirical Freundlich isotherm (Freundlich 1926) has been used widely to express data on nonmetabolic adsorption in many different systems. The mathematical relationship is given by

$$x/m = ac^b$$

$$\text{or} \qquad \log (x/m) = \log a + b \log c$$

where $x$ is the amount of solute taken up, $m$ is the unit mass of adsorbent, $c$ is the concentration of solute in solution, and $a$ and $b$ are constants for a specific system at constant temperature. As noted by Samuelson (1953), the validity of the adsorption isotherm is not proof of a physical adsorption (largely van der Waals forces), since uptake by ion exchange (that is, adsorption exchange) may give a similar pattern. Recently, Bachmann (1963) found the uptake of $Zn^{65}$ by freshwater plankton, detritus, and sediments to be best described by this expression.

$Zn^{65}$ uptake by *Ulva*, *Porphyra*, and cell walls of *Ulva* was found to fit the adsorption equation (Fig. 1). Also, it was found that killed seaweeds generally took up more $Zn^{65}$ than did living algae. Possible reasons for this are given elsewhere (Gutknecht 1963). In addition, empty cell walls of *Ulva* took up as much $Zn^{65}$ during an 8-hr period as did a similar number of living cells. These results are consistent with earlier data that suggested that nonmetabolic adsorption exchange plays an important role in $Zn^{65}$ uptake by seaweeds (Gutknecht 1961, 1963).

A plot of log Cs uptake vs. log external Cs concentration was also linear (Fig. 2). However, $x/m$ in this case did not increase less rapidly than $c$. That is, uptake was exactly proportional to external concentration, which is not likely in an adsorption-type reaction (Briggs, Hope, and Robertson 1961). Similar results were obtained with *Fucus*, *Ulva*, and *Porphyra*. Thus, these data are consistent with the above results on nonmetabolic $Cs^{137}$ adsorption and suggest that $Cs^{137}$ in seaweeds is mainly ionic and not extensively adsorbed.

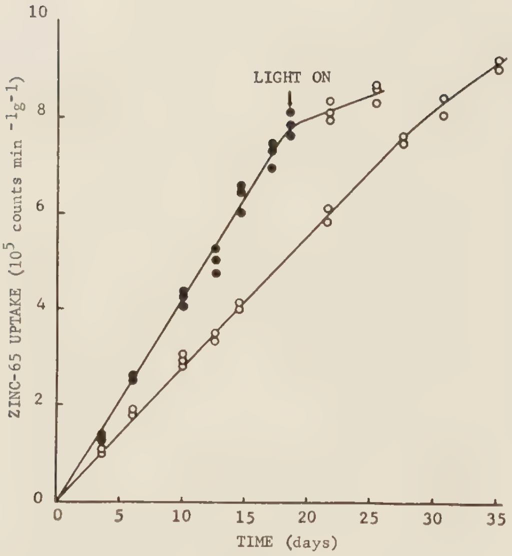

FIG. 3. Effect of light (○) and dark (●) on $Zn^{65}$ uptake by *Fucus*. Each point is the average of 2–3 branches.

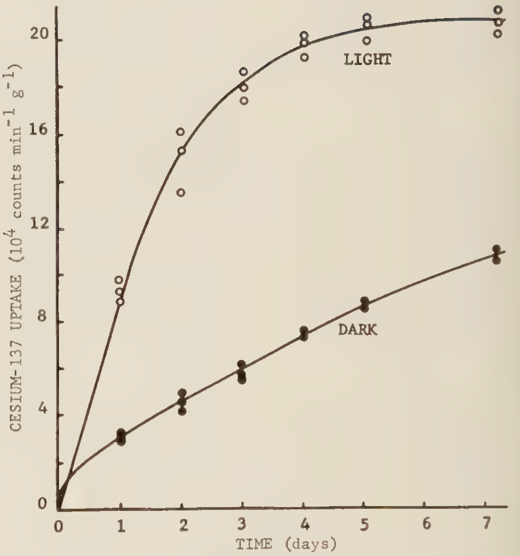

FIG. 4. Effect of light (○) and dark (●) on $Cs^{137}$ uptake by *Ulva*. Each point is the average of 6 discs of tissue.

### *Effects of metabolism on $Cs^{137}$ and $Zn^{65}$ uptake and retention*

Algae were exposed to $Cs^{137}$ and $Zn^{65}$ in both the light and the dark. It was found previously that in two fast-growing species, *Ulva* and *Porphyra*, the young tissue showed a higher $Zn^{65}$ activity than older tissue (Gutknecht 1963). In *Fucus*, however, the opposite was true, that is, nongrowing tissue concentrated $Zn^{65}$ at a higher rate than growing algae (Fig. 3). The explanation for this may derive from the physical structure of *Fucus* and its high affinity for zinc. Gelatinous algin, characteristic of brown algae, fills the intercellular spaces (Smith 1955) and may retard the attainment of equilibrium between the $Zn^{65}$ in the medium and the tissue. For example, it took 2–3 days for killed *Fucus* to reach equilibrium with $Zn^{65}$ in the medium, whereas killed tissue of other species in Table 1 became equilibrated in several hours. Also, the nonphotosynthesizing *Fucus* showed a gradual loss of weight (about 0.5%/day) without a concomitant loss of $Zn^{65}$. This would result in a gradually increasing concentration factor regardless of the normal steady-state level of $Zn^{65}$ in the plant.

$Cs^{137}$ uptake was stimulated by light in all species. This was first observed by Scott (1954), who suggested an intimate connection between the mechanisms of cesium accumulation and photosynthesis in *Rhodymenia*. Scott's observations, however, included a "virtual exclusion" of $Cs^{134}$ in the dark, an observation not confirmed with the present species. In some algae, for example, *Ulva* and *Porphyra*, $Cs^{137}$ accumulation after 7 days in the dark was from 30 to 60% of that in the light (Fig. 4). In some others, for instance, *Chondrus* and *Gracilaria*, $Cs^{137}$ uptake in the dark was much slower but was demonstrated by a comparison with $Cs^{137}$ uptake in a nitrogen atmosphere (Fig. 5).

The effects of anoxia (continuous bubbling with $N_2$ in the dark), exogenous substrate (monosodium glutamate, 50 mM), previous exposure to light (72 hr at 7,500 lux), nutrients ($PO_4^{-3}$ and $NO_3^-$ at 20 $\mu$M/liter), and continuous light (7,500 lux) were investigated in *Gracilaria*. Owing to the nonuniform cell population in *Gracilaria* (cells range from about 10 to 600 $\mu$ diameter), the determination of ion fluxes is difficult (*see* MacRobbie and Dainty 1958). To obtain relative values, however, the linear portions of the uptake-time curves were compared. Compared with the dark controls, light increased the rate of $Cs^{137}$ uptake by a factor of 45, glutamate increased uptake by a factor of 6.0, and anoxia decreased uptake by a factor of 0.31. Plants previously exposed to light and then placed in $Cs^{137}$ medium in the dark absorbed $Cs^{137}$ at an initial rate comparable to plants in the light, but after 20–30 hr, the rate of uptake decreased to a value similar to the dark controls. In agreement with the findings of Scott (1954), it was also found that small amounts of phosphate and nitrate slightly stimulate $Cs^{137}$ uptake in the light.

In *Gracilaria*, a plot of log per cent activity remaining vs. log time was linear (Fig. 6). Although the linearity of the full-log plot may be fortuitous, it provided a means of comparing loss rates over a period of several days. As compared with the dark control, $Cs^{137}$ efflux from 1 to 5 days was increased by a factor of 2.3–3.0 in the light and decreased by a factor of 0.57 in nitrogen. The fact that cells are dividing and enlarging in $Cs^{137}$ medium in the light may partly account for the relatively greater effect of light on uptake than on loss of $Cs^{137}$. Rice (1963*b*) showed that $Cs^{137}$ uptake by *Nannochloris* closely followed the growth of the cells.

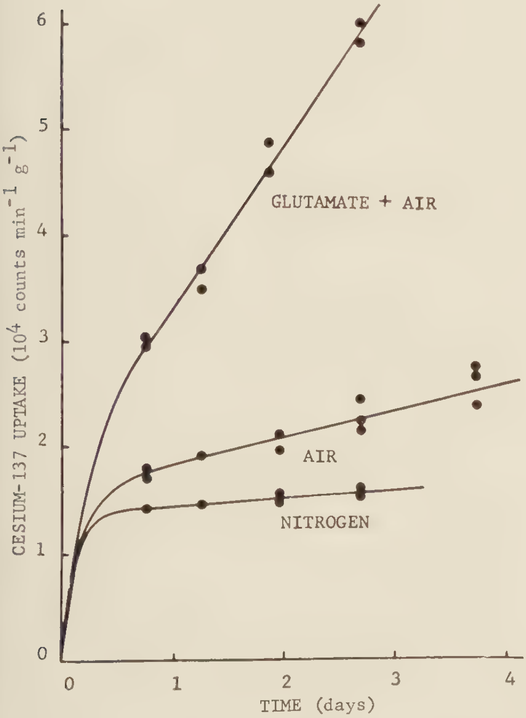

FIG. 5. Effects of anoxia and glutamate (50 mM) on $Cs^{137}$ uptake by *Gracilaria* in the dark. Each point is the average of 4–5 branches.

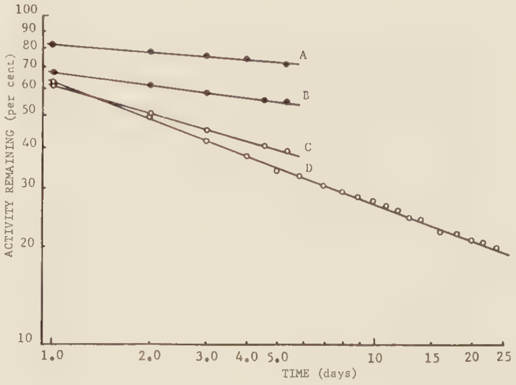

FIG. 6. Effects of anoxia (A), darkness (B), and light (C) and (D) on $Cs^{137}$ loss from *Gracilaria* (D is a separate experiment). Alga previously exposed to $Cs^{137}$ for 36 hr in the light. Each point is the average of 6 branches.

The effects of dark and anoxia on net movements of cesium were also investigated. *Gracilaria* that had accumulated $Cs^{137}$ for 6–9 days to a steady state in the light was kept in the same radioactive medium in aerated dark flasks and dark flasks bubbled with nitrogen. Less than 5% of the $Cs^{137}$ was lost from the alga either under anoxia (5 days) or in the dark (7 days). Thus, neither respiration nor photosynthesis was required to maintain an intracellular concentration factor of more than 25. However, as noted above, in the absence of air, and especially of light, both influx and efflux of $Cs^{137}$ were markedly reduced.

## DISCUSSION

### *Mechanism of $Cs^{137}$ and $Zn^{65}$ movements*

$Cs^{137}$ showed little tendency to be adsorbed by either living or freshly killed algae. However, if it is assumed that intracellular cesium is largely ionic, $Cs^{137}$ was accumulated against a concentration gradient in all species tested. This may not necessitate active transport of cesium, because negative intracellular potentials similar to those reported for *Rhodymenia* (MacRobbie and Dainty 1958) or *Halicystis* (Blount and Levedahl 1960) could account for passive accumulation of $Cs^{137}$ to the levels found in most species.

It was shown in Fig. 2 that $Cs^{137}$ uptake is proportional to external Cs concentration over a range of 0.01–100 $\mu$M. It was found also that efflux of $Cs^{137}$ is proportional to the intracellular cesium concentration. That is, algae which have accumulated $10^4$ times as much cesium as the controls lose cesium $10^4$ times as fast in natural seawater. Furthermore, it was found in double-label experiments that *Gracilaria*, while losing $Cs^{137}$-labeled cesium at a rate $10^4$ times that of the controls, absorbed carrier-free $Cs^{134}$ at a rate identical to that of the controls, that is, efflux initially exceeded influx by a factor of $10^4$. Therefore, an obligatory exchange of internal Cs for external Cs is not involved in cesium movements at these concentrations. However, the fact that in *Gracilaria* neither light, dark, nor anoxia resulted in net Cs movements indicates that the observed $Cs^{137}$ fluxes do involve an exchange of some type, probably with a more abundant cation such as $K^+$.

The highest external cesium concentration employed (100 $\mu$M) caused no reduction in the rate of $Cs^{137}$ uptake. If a carrier is involved in Cs transport, however, it is probably identical with the potassium carrier, as has been shown in many cell types. At an external Cs concentration of 100 $\mu$M, Cs influx in the light was about 75 $\mu$M/kg cell water × hr. In *Gracilaria*, this is less than 0.1% of the K influx (Gutknecht, unpublished data). Thus, the K carrier would be far from saturation with respect to Cs, a condition kinetically indistinguishable from free diffusion (Rosenberg and Wilbrandt 1955).

With regard to $Zn^{65}$, the present data are consistent with an earlier hypothesis that $Zn^{65}$ movements involve largely adsorption exchange, although $Zn^{65}$ turnover is to some extent related to metabolism (Gutknecht 1961, 1963). As indicated by the extensive uptake by living and killed tissues and cell walls, both the cytoplasm and extracellular components appear to have large numbers of potential binding sites for $Zn^{65}$. This might be expected, since the high affinity of zinc for organic ligands is well known (Goldberg 1957; Lowman 1960). In freshwater plankton and detritus, the mechanism appears similar (Bachmann 1963).

### *Environmental contamination by $Cs^{137}$ and $Zn^{65}$*

A knowledge of the steady-state concentration factor for a radionuclide in an organism aids in evaluating the hazards of fallout and waste disposal. As noted earlier, there is a considerable difference between the high CF values found for $Cs^{137}$ in living and killed freshwater algae (Williams and Swanson 1958; and others), and the low CF values found for marine algae (Boroughs, Chipman, and Rice 1957; and the present study). It was shown above that part of this variation is probably due to salinity differences. Part of it, however, is due to the method of determining the CF. As noted by Rice (1963*b*), in the experiments of Williams and Swanson the external $Cs^{137}$ concentration was markedly reduced because of uptake by the cells, thus proportionally increasing the final CF. In the experiments of Boroughs, Chipman, and Rice, and in the present study, the external $Cs^{137}$ concentration was constant.

In nature, either of the above conditions might occur, depending, for example, on whether the release of $Cs^{137}$ from a reactor was continuous or periodic. However, uptake during a short exposure in the light was more rapid than loss during a similar period in nonactive seawater. Therefore, a high level of environmental $Cs^{137}$ for a short time may have a disproportionately large effect on the contamination hazard. This was also true of $Zn^{65}$.

Sediments, light, *p*H, and nutrients will also influence the uptake and loss of these radionuclides in nature. In coastal waters, for example, the sediments will probably remove some $Cs^{137}$ (Duke, Ibert, and Rae 1963) and a large proportion of $Zn^{65}$ (Duke and Willis 1964). The variable effects of light and *p*H on $Zn^{65}$ uptake and loss have been shown in this and earlier studies (Gutknecht 1963). Similarly, studies on the uptake and retention of $Cs^{137}$ are complicated by the effects of light and, in some cases, by the presence of intracellular compartments that show different rates of $Cs^{137}$ turnover. In general, consideration might be given to releasing reactor wastes at night, since the uptake rates of $Zn^{65}$, and especially $Cs^{137}$, were usually higher in the light.

One natural means of reducing the hazard of a radionuclide in the ocean is the buffer action of seawater (Revelle 1955), also called the "specific activity approach" to waste disposal (Isaacs et al. 1962). The 700 megatons of cesium in the sea, for example, will greatly reduce the specific activity of any $Cs^{137}$ present in fallout or reactor wastes. In these experiments, however, adding stable Cs to reduce the specific activity of $Cs^{137}$ by a factor of $10^4$ did not reduce the amount of radioactivity absorbed. Thus, the benefits of isotopic dilution of $Cs^{137}$ were not demonstrated. Similar results were obtained in experiments with pinfish (*Lagodon rhomboides*), mummichog (*Fundulus heteroclitus*), and brine shrimp (*Artemia salina*) (Gutknecht, unpublished data). These results may be due to the relative abundance of K in seawater, a condition that simulates isotopic dilution (Lowman 1960). On the other hand, Kornberg (1961) claims there is no good evidence that Cs and K follow similar metabolic pathways.

### *Relationship of $Zn^{65}$ and $Cs^{137}$ uptake to photosynthesis*

As noted earlier, the uptake of both $Zn^{65}$ and $Cs^{134}$ by some seaweeds has been reported to depend on light (Bachmann and Odum 1960; Scott 1954). The variable amounts of these tracers absorbed in the dark, however, appear to make this hypothesis untenable for most species. It has been suggested that the reported relationship between $Zn^{65}$ uptake and photosynthesis in seaweeds may be mainly due to a *p*H increase in unbuffered light bottles and a consequent increase in $Zn^{65}$ uptake by adsorption exchange (Gutknecht 1961).

The relationship between $Cs^{137}$ movements and photosynthesis may also be indirect. Cesium transport appears to be closely related to metabolism, as indicated by the effects of light, previous exposure to light, exogenous substrate, and anoxia. However, the present data do not support Scott's (1954) hypothesis of an intimate connection between the mechanisms of Cs absorption and photosynthesis.

## REFERENCES

Bachmann, R. W. 1963. $Zn^{65}$ in studies of the freshwater zinc cycle, p. 485–496. *In* V. Schultz and A. W. Klement [eds.], Proceedings of the First National Symposium on Radioecology, Colorado State University 1961. Reinhold, New York.

———, and E. P. Odum. 1960. Uptake of $Zn^{65}$ and primary productivity in marine benthic algae. Limnol. Oceanog., **5**: 349–355.

Blinks, L. R. 1955. Photosynthesis and productivity of littoral marine algae. J. Marine Res., **14**: 363–373.

Blount, R. W., and B. H. Levedahl. 1960. Active sodium and chloride transport in the single celled marine alga *Halicystis ovalis*. Acta Physiol. Scand., **49**: 1–9.

Boroughs, H., W. A. Chipman, and T. R. Rice. 1957. Laboratory experiments on the uptake, accumulation and loss of radionuclides by marine organisms, p. 69–79. *In* The effects of atomic radiation on oceanography and fisheries. Natl. Acad. Sci. Natl. Res. Council Publ. No. 551, 137 p.

Briggs, G. E., A. B. Hope, and R. N. Robertson. 1961. Electrolytes and plant cells. Blackwell, Oxford. 217 p.

Davis, J. J. 1963. Cesium and its relationships to potassium in ecology, p. 539–556. *In* V. Schultz and A. W. Klement [eds.], Proceedings of the First National Symposium on Radioecology, Colorado State University 1961. Reinhold, New York.

Davy de Virville, Ad., and J. Feldmann [Eds.]. 1964. Proceedings of the Fourth International Seaweed Symposium, Biarritz 1961. Macmillan, New York. 467 p.

Duke, T. W. 1963. Sediment-sorption of radionuclides, p. 8–19. *In* Annual Report of the Bureau of Commercial Fisheries Radiobiological Laboratory, U.S. Fish and Wildlife Service, Fishery Circular. In press.

———, E. R. Ibert, and K. M. Rae. 1963. Availability of sediment-sorbed materials to marine biota, p. 171–174. *In* V. Schultz and A. W. Klement [eds.], Proceedings of the First National Symposium on Radioecology, Colorado State University 1961. Reinhold, New York.

———, and J. N. Willis. 1964. Experimental environments, p. 95–110. *In* U.S. Bureau of Commercial Fisheries Radiobiological Laboratory, Annual Report to the Atomic Energy Commission.

Dunster, H. J. 1958. The disposal of radioactive liquid wastes into coastal waters. Proc. Intern. Conf. Peaceful Uses At. Energy 2nd Geneva, 1958, **18:** 390–399.

Freundlich, H. 1926. Colloid and capillary chemistry. [Transl. from 3rd German ed. by H. S. Hatfield.] Methuen, London. 883 p.

Goldberg, E. D. 1957. Biogeochemistry of trace elements, p. 345–358. *In* J. W. Hedgpeth [ed.], Treatise on marine ecology and paleoecology, v. 1. Geol. Soc. Am. Mem. 67.

Gutknecht, John. 1961. Mechanism of radioactive zinc uptake by *Ulva lactuca*. Limnol. Oceanog., **6:** 426–431.

———. 1963. $Zn^{65}$ uptake by benthic marine algae. Limnol. Oceanog., **8:** 31–38.

Isaacs, J. D. [*Chairman*]. 1962. Disposal of low-level radioactive waste into Pacific coastal waters. Natl. Acad. Sci. Natl. Res. Council Publ. 985, 87 p.

Kornberg, H. A. 1961. The use of element-pairs in radiation hazard assessment. Health Phys., **6:** 46–62.

Kraus, K. A., and G. E. Moore. 1953. Anion exchange studies. VI. The divalent transition elements manganese to zinc in hydrochloric acid. J. Am. Chem. Soc., **75:** 1460–1462.

Krumholz, L. A. 1954. An ecological survey of White Oak Creek, 1950–1953. At. Energy Comm. Tech. Doc. ORO-587, v. 1, 208 p.

Kuenzler, E. J., and B. H. Ketchum. 1962. Rate of phosphorus uptake by *Phaeodactylum tricornutum*. Biol. Bull., **123:** 134–146.

Laties, G. C. 1959. Active transport of salt into plant tissue. Ann. Rev. Plant Physiol., **10:** 87–112.

Lowman, F. G. 1960. Marine biological investigations at the Eniwetok test site. Proc. Sci. Conf. Disposal Radioactive Wastes, Monaco, 1959, **2:** 106–138. International Atomic Energy Agency, Vienna.

MacRobbie, E. A. C., and J. Dainty. 1958. Sodium and potassium distribution and transport in the seaweed *Rhodymenia palmata*. Physiol. Plantarum, **11:** 782–801.

Nason, A., and W. D. McElroy. 1963. Modes of action of the essential mineral elements, p. 451–522. *In* F. C. Steward [ed.], Plant physiology, v. 3. Academic, New York.

Odum, E. P., and F. B. Golley. 1963. Radioactive tracers as an aid to the measurement of energy flow at the population level in nature, p. 403–410. *In* V. Schultz and A. W. Klement [eds.], Proceedings of the First National Symposium on Radioecology, Colorado State University 1961. Reinhold, New York.

Relman, A. S. 1956. The physiological behavior of rubidium and cesium in relation to that of potassium. Yale J. Biol. Med., **29:** 248–262.

Revelle, R. R. D. 1955. Disposal in the sea (discussion section). Proc. Intern. Conf. Peaceful Uses At. Energy 1st Geneva, 1955, **9:** 722–724.

Rice, T. R. 1956. The accumulation and exchange of strontium by marine planktonic algae. Limnol. Oceanog., **1:** 123–138.

———. 1963*a*. Review of zinc in ecology, p. 619–631. *In* V. Schultz and A. W. Klement [eds.], Proceedings of the First National Symposium on Radioecology, Colorado State University 1961. Reinhold, New York.

———. 1963*b*. Accumulation of radionuclides by aquatic organisms, p. 35–50. *In* Studies of the fate of certain radionuclides in estuarine and other aquatic environments. Public Health Service Publication 999-R-3, U.S. Dept. of Health, Education, and Welfare, Washington, D.C., 73 p.

Rosenberg, T., and W. Wilbrandt. 1955. The kinetics of membrane transports involving chemical reactions. Exp. Cell. Res., **9:** 49–67.

Samuelson, O. 1953. Ion exchangers in analytical chemistry. Wiley, New York. 291 p.

Scott, R. 1954. A study of cesium accumulation by marine algae, p. 373–380. *In* J. E. Johnston [ed.], Proc. 2nd Radioisotope Conf., Oxford, I, Med. Physiol. Applications. Butterworths, London.

Smales, A. A., and L. Salmon. 1955. Determination by radioactivation of small amounts of rubidium and cesium in seawater and related materials of geochemical interest. Analyst, **80:** 37–50.

Smith, G. M. 1955. Cryptogamic botany, 2nd ed., v. 1. McGraw-Hill, New York. 546 p.

Vallee, B. L. 1962. Zinc, p. 443–472. *In* C. L. Comar and F. Bronner [eds.], Mineral metabolism, an advanced treatise, v. 2, Part B. Academic, New York.

———, and J. G. Gibson. 1948. An improved dithizone method for the determination of small quantities of zinc in blood and tissue samples. J. Biol. Chem., **176:** 435–443.

Wiessner, W. 1962. Inorganic micronutrients, p. 267–286. *In* R. A. Lewin [ed.], Physiology and biochemistry of algae. Academic, New York.

Williams, L. G. 1960. Uptake of $Cs^{137}$ by cells and detritus of *Euglena* and *Chlorella*. Limnol. Oceanog., **5:** 301–312.

———, and H. D. Swanson. 1958. Concentration of cesium-137 by algae. Science, **127:** 187–188.

# ION DISTRIBUTION AND TRANSPORT IN THE RED MARINE ALGA, GRACILARIA FOLIIFERA

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# ION DISTRIBUTION AND TRANSPORT IN THE RED MARINE ALGA, GRACILARIA FOLIIFERA [1, 2]

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Marine algae were the object of many early studies of electrolyte permeability and transport (see Blinks, 1940; Osterhout, 1940). However, there have been few recent investigations of ionic relations in marine algae. In *Ulva* and *Hormorsira* independent and oppositely directly $Na^+$ and $K^+$ transport systems were proposed (Scott and Hayward, 1954, 1955; Bergquist, 1958, respectively). *Porphyra,* a non-vacuolated red alga, actively extruded $Na^+$ and passively accumulated $K^+$ (Eppley, 1958a. 1958b, 1959, personal communication). MacRobbie and Dainty (1958a, 1958b) demonstrated active efflux of $Na^+$ and active influx of $Cl^-$ in *Rhodymenia,* a vacuolated red alga, and in *Nitellopsis,* a brackish water characean. *Halicystis* actively extruded $Na^+$ and actively absorbed $Cl^-$, whereas $K^+$ was in electrochemical equilibrium between vacuole and sea water (Blount and Levedahl, 1960).

In some, but not all, of these studies membrane potential measurements were made in conjunction with ion distribution and flux measurements. As pointed out by Ussing (1960) and Dainty (1962), this information is needed to determine exactly which ions are actively transported, *i.e.*, moved against an electrochemical potential gradient.

This is a study of alkali and halide ion transport in *Gracilaria foliifera,* a red marine alga. The major monovalent ions, $Na^+$, $K^+$ and $Cl^-$, are included, as well as the less abundant ions, $Rb^+$, $Cs^+$, $Br^-$ and $I^-$. The latter were included for comparative purposes and also because of their radiobiological importance as components of fallout and nuclear reactor wastes. A primary objective of this work was to determine which of these ions are actively transported by cells of *Gracilaria.* The major criterion for active transport was the existence of an appreciable difference between the calculated Nernst equilibrium potential for each ion and the measured vacuole potential. The effects of some environmental factors, mainly light and anaerobiosis, on ion fluxes and their rate coefficients were studied also.

*Gracilaria foliifera* is a red seaweed common on the North Carolina Coast. Its slightly compressed branches are composed of large vacuolated cells, 100–150 $\mu$ in diameter, surrounded by several layers of small cells, 10–20 $\mu$ in diameter, and a tough outer cuticle. Visual estimates indicate that the vacuoles of the large cells comprise more than half the tissue volume. Most of the remaining volume, as shown below, is extracellular space and some impermeable material. The protoplasm comprises only a small fraction of the tissue.

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## METHODS

### *Experimental procedure*

*Gracilaria* was collected from rock jetties near the Beaufort harbor inlet and placed in 40-liter plastic tanks containing aerated sea water. Constant illumination was provided by two 40-watt "daylight" fluorescent tubes placed about 60 cm. from the seaweed. Water temperature ranged from 15° to 20° C. The alga was kept under these conditions for several months without apparent deterioration.

Experiments were conducted with small branches of the seaweed, 3–4 cm. and 10–30 mg. each, contained in 2-liter flasks of aerated medium. The basic medium was natural sea water (salinity 32–35‰), buffered at pH 7.8–7.9 with tris(hydroxymethyl)aminomethane (10 m$M$) and containing added $NaNO_3$ (100 $\mu M$) and $NaH_2PO_4$ (50 $\mu M$). The test solutions were changed daily. Experiments were conducted either in the dark (flasks painted black) or under constant illumination of 8500 ± 1000 lux provided by six 40-watt "daylight" tubes, 20–30 cm. from the flasks. The experimental temperature was 24 ± 1° C. Under these conditions the growth rate in the light was 0.5–1.0%/hr., whereas no detectable growth occurred in the dark.

Sodium and potassium were measured by flame photometry (Beckman DU spectrophotometer with flame attachment),[3] and chloride was measured with an Aminco-Cotlove automatic chloride titrator. Sodium and potassium were extracted by soaking tissues overnight in $HNO_3$ (1.0 or 0.2 N). Chloride was extracted either by this method or with hot distilled water. Similar results were obtained with both methods.

Cesium, $Rb^+$ and $I^-$ were not measured chemically. The relative intracellular concentration of these elements was determined by radioactivity measurements, and is expressed as a concentration ratio (c.p.m./g. cell water):(c.p.m./ml. environment). The natural concentrations of $Cs^+$ and $Rb^+$ in sea water are about 0.04 $\mu$eq./l. and 1.4 $\mu$eq./l., respectively (Smales and Salmon, 1955). The total iodine concentration in sea water is about 0.4 $\mu$eq./l. (Barkely and Thompson, 1960; Sugawara *et al.*, 1962).

Gamma-emitting radioisotopes ($Cs^{137}$, $Rb^{86}$, $K^{42}$, $Br^{82}$ and $Na^{22}$) were measured in a 3-inch well-type scintillation detector connected to a single-channel analyzer (Baird-Atomic Model 510). Tissues were removed periodically from the flasks, blotted with absorbent tissue, wrapped in plastic, counted, weighed and returned to their solutions. Carbon-14 and $Cl^{36}$ were measured in an end-window gas flow detector with a low-background attachment (Nuclear Chicago Model C-115). Several 1-ml. aliquots of neutralized tissue extract or medium were dried in planchets for counting.

Radioisotopes were purchased from the Oak Ridge National Laboratory, Oak Ridge, Tenn. ($K^{42}$, $Rb^{86}$, $Cs^{137}$, $Cl^{36}$, $Br^{82}$ and $I^{131}$); Nuclear Science and Engineering, Pittsburgh, Pa. ($Na^{22}$); and Calbiochem, Los Angeles, Cal. ($C^{14}$-mannitol and $C^{14}$-sucrose). Tracers were either "carrier-free" or of sufficiently high specific activity so that the natural concentration of the element was increased less than 3%.

The electrical potential of the vacuole was measured with glass microcapillary electrodes and a high-impedance voltmeter (Keithley Model 600A). Pipettes with tip diameters of 4–8 $\mu$ were drawn from 1 mm. Pyrex tubing and filled with

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[3] Trade names referred to in this publication do not imply endorsement.

0.5 *M* KCl by boiling under reduced pressure. The pipette was connected to the voltmeter by a KCl-agar bridge and calomel half-cell. An identical half-cell and sea-water-agar bridge completed the circuit, making contact with the bathing sea water which was taken as ground. The electrodes had tip potentials of less than 2 mv. in either sea water or 0.5 *M* KCl.

To measure the vacuole potential, a branch was held rigidly with waterproof putty in a glass dish of sea water under a dissecting microscope. The cells were exposed by an oblique cross-sectional cut, and the puncture was made with the aid of a micromanipulator. Ten to 20 minutes were usually required for the potential to reach a stable value. After this, only potentials which were stable (±1 mv.) for at least 30 minutes were recorded.

### *Estimation of ion fluxes and rate coefficients*

The difficulties of estimating ion fluxes and their rate constants in a heterogeneous cell population were emphasized by MacRobbie and Dainty (1958a) in their study of $Na^+$ and $K^+$ fluxes in the seaweed *Rhodymenia.* Since their admonitions apply also to the tissues of *Gracilaria,* fluxes were estimated in terms of cell water rather than in terms of membrane area. Also, rate constants, or rate coefficients (since they varied with time), were measured during successive time intervals and averaged.

Unidirectional fluxes were estimated for the ions in which specific activities were known ($Na^+$, $K^+$ and $Cl^-$), using the relations

$$M_i = \frac{C_i^*}{t} \frac{C_o}{C_o^*}$$

$$M_o = k_o C_i$$

where $M_i$ and $M_o$ are the initial influx and efflux in meq. (kg. cell water)$^{-1}$ hours$^{-1}$; $C_o^*$ and $C_o$ are the labeled ion and total ion concentrations outside; $C_i$ is the total intracellular ion concentration; $C_i^*$ is the labeled ion concentration inside the cells at time, $t$; and $k_o$ is the rate of coefficient for efflux, calculated as shown below. Influx values were calculated by using data from the early portion of isotope uptake experiments, when the efflux of labeled ions was considered negligible.

Rate coefficients for isotope influx ($k_i$) and efflux ($k_o$) were calculated from the equations

$$k_i = \frac{2.3}{t} \log \frac{C_{i,oo}^*}{C_{i,oo}^* - C_i^*}$$

$$k_o = \frac{2.3}{t} \log \frac{C_{i,0}^*}{C_i^*}$$

where $C_{i,oo}^*$ is the intracellular labeled ion concentration at isotopic equilibrium; $C_{i,0}^*$ is the initial intracellular labeled ion concentration; and $C_i^*$ and $t$ have the same meanings as before. The two rate coefficients, one calculated from isotope influx data and the other from isotope efflux data, provided a means of comparing the unidirectional fluxes of ions for which specific activities were not known ($Cs^+$, $Rb^+$, $Br^-$ and $I^-$).

These equations are similar to those used recently by House (1963). They are derived from standard flux equations, treating the cells as a single compartment (see, for example, Sheppard, 1962). In experiments involving tracer efflux into a large nonlabeled environment, the usual plot of log activity remaining *vs.* time was often nearly linear, indicating fairly good agreement with predicted single-compartment behavior.

## RESULTS

### *Tissue water, extracellular space and cell water*

To estimate intracellular ion concentrations, the amounts of tissue water and extracellular space must be known. Tissue water, measured by comparing the fresh weight (after blotting with absorbent tissue) with the dry weight (24 hr. at 105° C.), was found to be 89 ± 1% (6). (Results are quoted in the sequence: mean, standard error and [in parentheses] number of measurements.)

Extracellular space (mainly the free space in the cell walls and between the cells) was measured by soaking tissues for 2–3 hours in sea water containing $C^{14}$-mannitol or $C^{14}$-sucrose. Tissues were then blotted, weighed, and washed in 50 ml. unlabeled sea water. From the amount of $C^{14}$ which diffused from the tissues to the environment (loss was complete after 15–30 minutes), it was calculated that the tissue contained 19 ± 2% (5) sucrose or mannitol space. The same method applied to tissues freshly killed (by immersing for 10 seconds in sea water at 90° C.) gave a value of 91 ± 2% free space, suggesting that about 9% of the tissue was impermeable to the labeled sugar. Although the agreement may be fortuitous, the latter value is close to the 11% dry weight found above.

Extracellular space also was checked by using $Na^{22}$, $Cl^{36}$ and $Br^{82}$. The amounts of these ions washed out in 8–10 minutes with either 0.6 *M* sucrose or unlabeled sea water agreed with the amounts predicted on the basis of 19% sucrose or mannitol space. This supports the assumptions that ion concentrations in the extracellular space are similar to those in sea water and that exchange of intracellular ions during a 10-minute wash in sucrose or sea water is insignificant. The other ions studied ($Rb^+$, $Cs^+$, $K^+$ and $I^-$) were predominantly intracellular, so that some extracellular adsorption (although there was little indication of this) would not appreciably affect the estimated intracellular ion concentrations.

Cell water was estimated, using the above figures, to comprise 69–71% of the tissue (*i.e.*, the difference between per cent tissue water and per cent extracellular space). Therefore, the intracellular ion concentrations were calculated as 100/70 = 1.4 times the tissue ion concentration, either following a 10-minute wash in 0.6 *M* sucrose or after subtracting the estimated concentration of ions in the extracellular space.

### *Electrical potential of the vacuole*

The vacuole potential, measured by means of microcapillary electrodes, was −81 ± 2 mv. (12). The highest recorded potential was −92 mv. The measurements were usually made after 12–48 hours of illumination, although several hours of darkness had no obvious effect on the potential.

### *Ion distribution and equilibrium potentials*

The concentrations of monovalent ions in *Gracilaria* and in sea water are shown in Table I. Concentration ratios ($C_i/C_o$) are based either on chemical and radioactivity measurements ($Na^+$, $K^+$ and $Cl^-$) or on radioactivity measurements alone ($Rb^+$, $Cs^+$, $Br^-$ and $I^-$). The $C_i/C_o$ values obtained in tracer experiments represent the steady-state levels attained in the light (after 10 hours to 9 days exposure, depending upon the ion). Chemical measurements of $Na^+$, $K^+$ and $Cl^-$ were made after about 48 hours illumination.

Potassium, the principal intracellular cation in *Gracilaria,* was concentrated about 60-fold (Table I). Sodium, in contrast, was excluded by a factor of about seven. Chloride, the principal intracellular anion, was present at over 60% of the concentrations of $Na^+$ plus $K^+$. About 70% of the tissue $Na^+$ and 25% of the tissue $Cl^-$ were extracellular. Rubidium, $Cs^+$ and $I^-$ were all highly concentrated by cells of *Gracilaria,* although they were of little quantitative importance compared to $Na^+$, $K^+$ and $Cl^-$.

TABLE I

*Concentrations and equilibrium potentials of monovalent ions in Gracilaria and in sea water**, **

| Ion | Sea water (meq./l.) ($C_o$) | *Gracilaria* (meq./kg. fresh wt.) | *Gracilaria* (meq./kg. cell $H_2O$) ($C_i$) | Concentration ratio ($C_i/C_o$) | Equilibrium potential (mv.) ($E_j$) |
|---|---|---|---|---|---|
| $Na^+$ | 471 ± 11 (11) | 161 | 66.3 ± 4.6 (13) | 0.14 ± 0.01 (11) | +50 |
| $K^+$ | 11.0 ± 0.2 (9) | 488 | 680 ± 12 (12) | 61.8 ± 1.1 (9) | −105 |
| $Rb^+$ | $1.4 \times 10^{-3}$ | — | — | 148 ± 5 (19) | −127 |
| $Cs^+$ | $0.04 \times 10^{-3}$ | — | — | 28.6 ± 2.5 (8) | −85 |
| $Cl^-$ | 532 ± 3 (8) | 436 | 462 ± 17 (8) | 0.87 ± 0.03 (8) | −3.6 |
| $Br^-$ | 0.81 | — | — | 0.57 ± 0.03 (4) | −14 |
| $I^-$ | $0.4 \times 10^{-3}$ | — | — | 150 ± 7 (4) | +128 |

* Sea water concentrations of $Rb^+$, $Cs^+$, $Br^-$, and $I^-$ are approximate, based on published values. Concentration ratios for these ions, based on radioactivity measurements, are more accurate, however.

** Results expressed as mean, S.E. and (in parentheses) number of measurements.

An equilibrium potential may be calculated for each ion, using an approximation of the Nernst equation

$$E_j = \frac{-2.3\ RT}{z_j F} \log \frac{C_i}{C_o}$$

where $E_j$ is the electrical potential across a membrane separating an ion at two concentrations, $C_i$ and $C_o$. The constants $R$, $T$, and $F$ have their usual meanings, and $z_j$ is the algebraic valency of the ion, $j$. An appreciable difference between the vacuole potential ($E$) and the equilibrium potential ($E_j$) indicates that the ion is not in passive flux equilibrium across the membrane and suggests, therefore, active transport of that ion (see Dainty, 1962).

Most of the calculated equilibrium potentials shown in Table I do not agree

TABLE II

*Rate coefficients for isotope fluxes in Gracilaria. Effects of light and darkness**, ***

| Ion | Rate coeff. of isotope influx ($k_i$) | Rate coeff. of isotope efflux ($k_o$) | |
|---|---|---|---|
| | Light | Light | Dark |
| $Na^+$ | 30 ± 1 (9) | 80 ± 9 (8) | 14 ± 4 (6) |
| $K^+$ | 20 ± 2 (6) | 9.8 ± 0.5 (7) | 0.47 ± 0.09 (5) |
| $Rb^+$ | 1.6 ± 0.2 (11) | 0.67 ± 0.1 (13) | 0.09 ± 0.02 (4) |
| $Cs^+$ | 1.9 ± 0.2 (9) | 0.46 ± 0.05 (14) | 0.22 ± 0.08 (4) |
| $Cl^-$ | 1.8 ± 0.1 (9) | 0.58 ± 0.1 (6) | 0.14 ± 0.03 (5) |
| $Br^-$ | 0.81 ± 0.08 (7) | 0.88 ± 0.08 (5) | 0.35 ± 0.05 (5) |
| $I^-$ | 2.5 ± 0.3 (5) | 0.55 ± 0.04 (3) | 0.21 ± 0.06 (3) |

* Units are $10^2 hr.^{-1}$.
** Results expressed as mean, S.E. and (in parentheses) number of measurements.

with the measured vacuole potential of −81 mv. Of the major ions, $Na^+$ is farthest from electrochemical equilibrium, both electrical and chemical gradients being directed inward. This suggests that $Na^+$ is actively transported out of the cells. Potassium, $Rb^+$, $Cl^-$ and $Br^-$ are all concentrated inside at considerably higher levels than would be predicted from the vacuole potential of −81 mv. Cesium is close to electrochemical equilibrium, and the status of $I^-$ is uncertain since, as is shown below, there is appreciable intracellular binding of $I^-$. Thus $K^+$, $Rb^+$, $Cl^-$ and $Br^-$ appear to be actively absorbed by cells of *Gracilaria,* and $Na^+$ appears to be actively extruded.

To justify using the Nernst equation, major shifts in ion distribution should not occur under the experimental conditions. To check this, tissues were illuminated for 48 hours, then kept for 5 days in the dark, and also under nitrogen in the dark. Under these conditions the intracellular $K^+$ and $Cl^-$ concentrations decreased less than 10%. Similarly, there was a net loss of about 5% of the radioactive $Rb^+$ and $Cs^+$ from maximally labeled tissues which were kept for 5 days under the same two conditions, in a constant radioactive environment. Intracellular $Na^+$ decreased in the dark from about 70 to 50 meq./kg. cell water, and increased under nitrogen from about 70 to 90 meq./kg. cell water. The net ion movements were slow compared to the unidirectional fluxes given below. Thus, under the conditions of this study, intracellular ion concentrations remained approximately constant.

TABLE III

*Ion fluxes in Gracilaria. Effects of light and darkness**, **

| Ion | Influx ($M_i$) | | Efflux ($M_o$) | |
|---|---|---|---|---|
| | Light | Dark | Light | Dark |
| $Na^+$ | 18 ± 2 (5) | 2.1 ± 0.3 (4) | 54 ± 6 (8) | 8.8 ± 2.5 (6) |
| $K^+$ | 101 ± 2 (8) | 9.1 ± 3.1 (6) | 66 ± 4 (7) | 3.2 ± 0.5 (5) |
| $Cl^-$ | 2.0 ± 0.5 (6) | 1.0 ± 0.4 (5) | 2.7 ± 0.5 (6) | 0.62 ± 0.2 (5) |

* Units are meq. (kg. cell water)$^{-1}$hr.$^{-1}$.
** Results expressed as mean, S.E. and (in parentheses) number of measurements.

Another requirement for calculating equilibrium potentials is that intracellular ions be in solution rather than adsorbed or bound to cytoplasmic sites. In *Gracilaria* intracellular ion binding was expected to be small, since the cytoplasm comprises only a small fraction of the large vacuolated cells. With $K^{42}$, $Rb^{86}$ and $Cs^{137}$ this was substantiated by the observation that maximally labeled tissues, when killed and held in the same radioactive environment, lost virtually all of their radioactivity

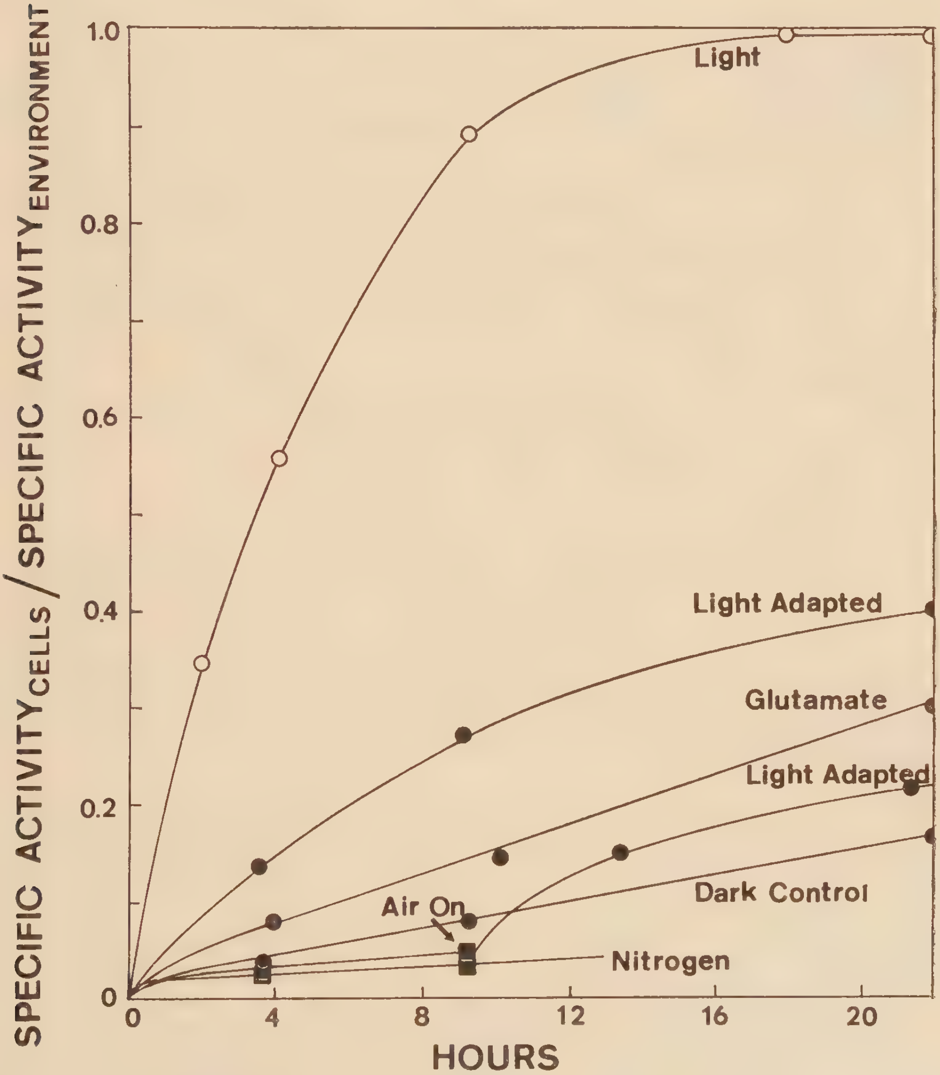

FIGURE 1. Potassium-42 uptake by cells of *Gracilaria*. Effects of light (8500 lux ) (○), darkness (●), anaerobiosis (nitrogen) (■), glutamate (50 m*M*), and previous exposure to light (20 hours at 8500 lux). Arrow indicates the addition of air to tissues previously exposed to light, then placed in a $K^{42}$ environment under nitrogen. Each point represents a measurement of 30–40 branches.

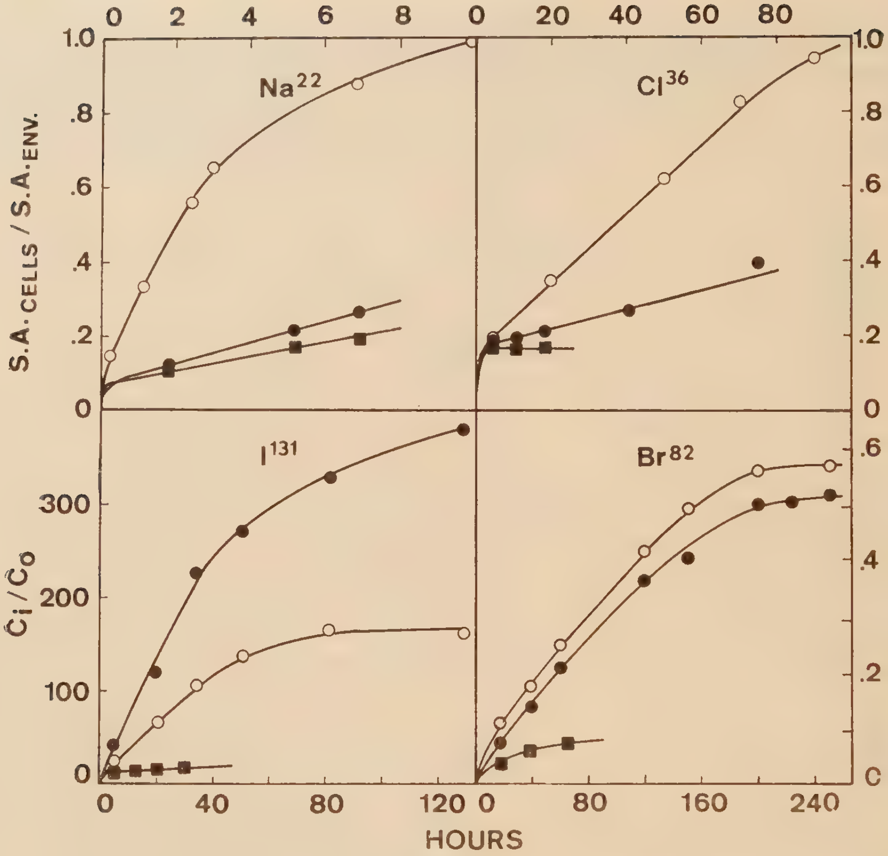

FIGURE 2. Uptake of $Na^{22}$, $Cl^{36}$, $Br^{82}$ and $I^{131}$ by cells of *Gracilaria*. Effects of light (○), darkness (●), and anaerobiosis (■). Radioactivity of cells expressed as a concentration ratio ($C_i/C_o$) or as the ratio of the specific activity (S.A.) of the cells to the S.A. of the environment. Each point represents a measurement of 15–40 branches. Note the differences in time and radioactivity scales.

in 20–30 minutes. Possible adsorption of the trace elements $Rb^+$ and $Cs^+$ was checked also by exposing the tissues to a wide range of low concentrations (0.01–100 $\mu$eq./l.). The uptake data, plotted as a Freundlich adsorption isotherm (Freundlich, 1926), gave linear log $C_i$ *vs.* log $C_o$ curves with a slope of 1.0 (Gutknecht, 1965). In other words, uptake over this range of concentrations was exactly proportional to external concentration, which is not likely in an adsorption-type reaction (Briggs, Hope and Robertson, 1961).

Iodide-131, in contrast to the other ions studied, was at least partly bound. Maximally labeled tissues, when killed and held in their original radioactive environment, retained about 25% of their radioactivity. Interestingly, tissues exposed to $I^{131}$ in the dark contained a much larger amount of bound radioactivity. This difference was reflected in a higher rate of uptake as well as a higher $C_i/C_o$ of 416 ± 20 (4), compared to the value of 150 found in the light (Table I).

All of the $Na^+$, $K^+$ and $Cl^-$ in *Gracilaria* appeared to be exchangeable in the light. The specific activities of the tissues and environment became equal after exposure periods of about 10 hours for $Na^{22}$, 20 hours for $K^{42}$ and 100 hours for $Cl^{36}$. In general, all the ions except $I^-$ appeared to be unbound and exchangeable and are no doubt largely in solution in the vacuolar sap. It is not likely, therefore, that ion binding plays an important role in determining the steady-state distribution of ions in *Gracilaria*.

### *Ion fluxes and rate coefficients*

Ion fluxes were measured in the light (8500 lux), dark and under anaerobic conditions (continuous bubbling with commercial nitrogen in the dark). The effects of previous exposure to light, as well as the effects of exogenous substrate

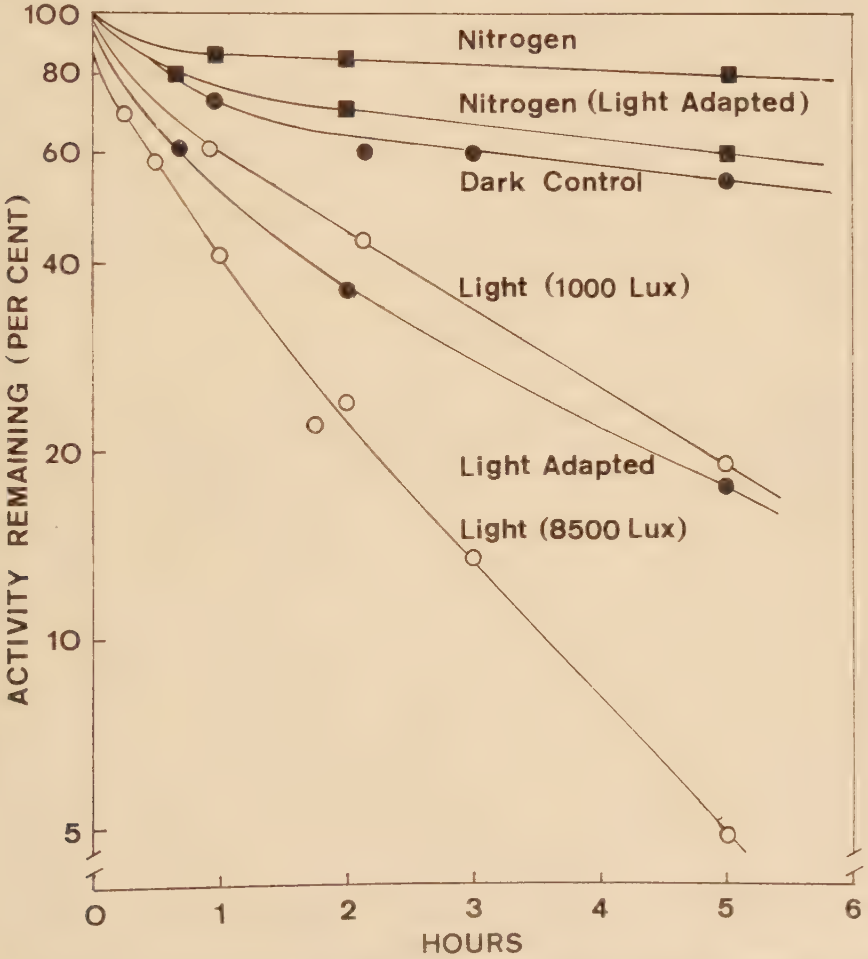

FIGURE 3. Loss of intracellular $Na^{22}$ from *Gracilaria*. Effects of light (8500 lux to 1000 lux) (○), darkness (●), previous exposure to light (48 hours at 8500 lux), anaerobiosis (■), and anaerobiosis after previous exposure to light. Each point represents a measurement of 30–40 branches.

(sodium glutamate, 50 *mM*), were studied in some experiments. Unless otherwise indicated, tissues were adapted for 36–48 hours in either the light or dark, depending upon the subsequent experimental conditions. This conditioning was important since the effect of light on ion movements persisted during 10–20 hours of subsequent darkness.

Average fluxes and rate coefficients were calculated as described, and are listed in Tables II and III. Figures 1–4 show graphically the movements of labeled ions under various environmental conditions. The exchange of extra-

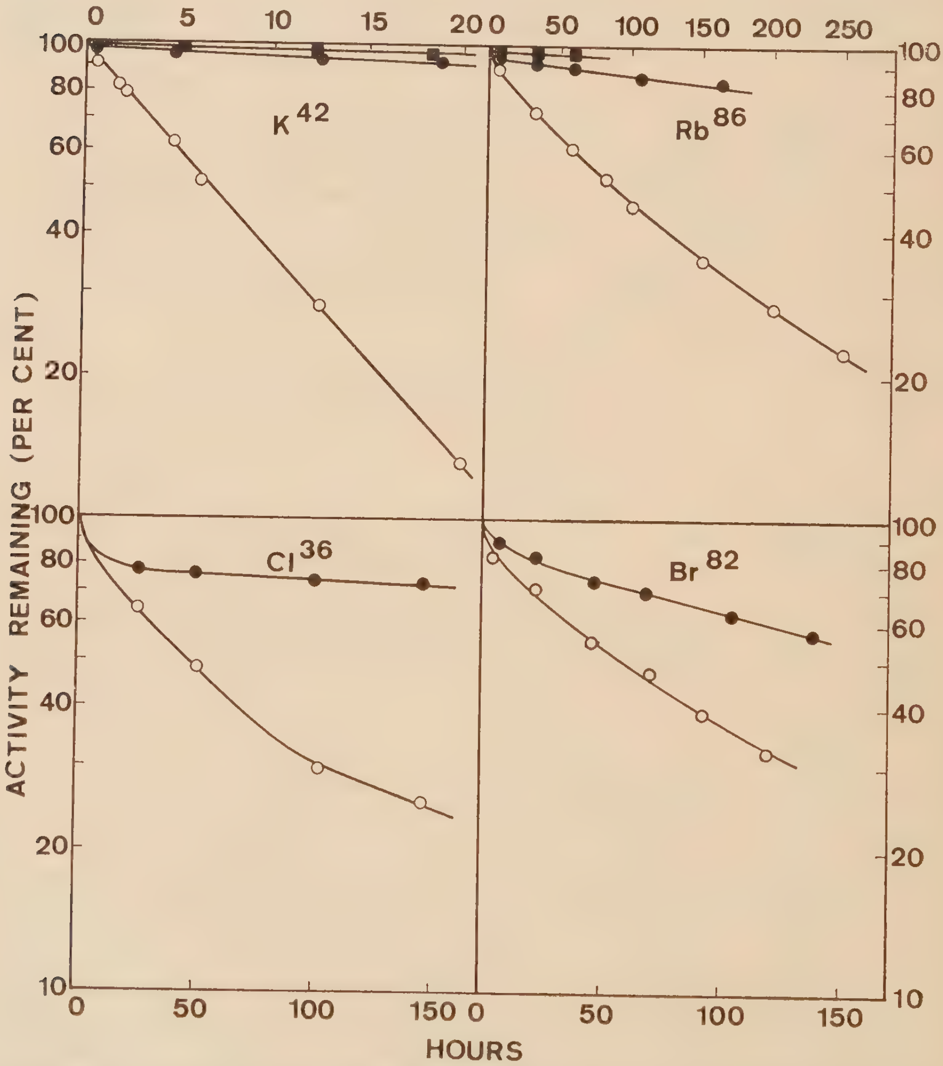

FIGURE 4. Loss of intracellular $K^{42}$, $Rb^{86}$, $Cl^{36}$ and $Br^{82}$ from *Gracilaria*. Effects of light (○), darkness (●), and anaerobiosis (■). Each point represents a measurement of 15–40 branches. Note the differences in time scales.

cellular ions is not included in either the figures or the tables, since the tissues were washed before counting. Nevertheless, a small and relatively fast intracellular compartment, or "shoulder," was often evident in both isotope uptake and loss experiments (see Figs. 1–4). This fast compartment also was excluded from the calculations of ion fluxes and rate coefficients. This compartment was generally less sensitive to environmental conditions than was the large slower compartment (presumably the vacuoles of the large cells).

Light promoted both influx and efflux of cations, as well as the efflux of anions (Figs. 1–4, Tables II and III). The effect of light on anion influx was variable, *i.e.*, $Cl^-$ uptake was promoted by light, $Br^-$ uptake was only slightly affected, and $I^-$ uptake was depressed (Fig. 2). Anaerobiosis depressed the influx and efflux of cations and the influx of anions by factors ranging from 0.1 to 0.8, compared to the dark controls (Figs. 1–4).

Previous exposure to light had a temporary stimulating effect on $K^+$ influx and $Na^+$ efflux (Figs. 1 and 3). However, light-adapted cells placed in a radioactive environment under nitrogen did not show the temporary stimulation of the $K^+$ or $Na^+$ flux unless air was provided (Figs. 1 and 3). In the dark, glutamate (50 m$M$) increased the $K^+$ and $Na^+$ influx 2–3 times, compared to controls.

In general, the movements of $Na^+$, $K^+$, $Rb^+$ and $Cs^+$ were affected in a qualitatively similar manner by each of the environmental conditions shown in Figure 1. The major difference was that the rate coefficients for isotope influx and efflux decreased markedly in the order $Na^+ > K^+ > Rb^+, Cs^+$ (Table III).

## Discussion

All of the major ions ($Na^+$, $K^+$ and $Cl^-$) appear to be actively transported in *Gracilaria*, as indicated by the large differences between the vacuole potential (−81 mv.) and the equilibrium potentials shown in Table I. Sodium, as in most plant and animal cells, is farthest from electrochemical equilibrium ($E - E_{Na} = -131$ mv.), and is extruded against both electrical and chemical gradients. Active $Cl^-$ absorption is indicated ($E - E_{Cl} = -77$ mv.), which is in contrast to most animal, but not plant, cells (see Dainty, 1962). Potassium, which is usually close to electrochemical equilibrium in both plant and animal cells, appears also to be actively absorbed ($E - E_K = 24$ mv.).

One of the assumptions on which the above interpretations rest was that the influx and efflux of an ion are equal. Although this was approximately true, there were some apparent deviations (Tables II and III). These may be due to net ion uptake with growth, as well as to errors involved in estimating fluxes and rate coefficients in a heterogeneous cell population. An alternative value, however, for the predicted vacuole potential, $E_j$, can be calculated by using the Ussing-Teorell flux-ratio equation (see Dainty, 1962, p. 384). The values for $E_j$ obtained with this equation make even more stringent the requirements for active transport of most of the ions. That is, the $E - E_j$ values are larger than those obtained using the Nernst equilibrium potentials. The only exceptions were that $E - E_{Cl}$ decreased from −77 to −70, and $E - E_{Br}$ decreased from −67 to −65.

A second assumption was that selective binding of ions does not appreciably alter the estimated intracellular concentrations, especially of $K^+$ and $Rb^+$. (Any intracellular binding of $Na^+$ would make the requirements for active $Na^+$ extrusion even more stringent.) This was shown to be unlikely, since killed cells quickly lost all of their accumulated $K^+$ and $Rb^+$, and since (in the case of $Rb^+$) uptake was exactly proportional to external concentration over a wide range of low concentrations.

The third possible error could arise from a large difference between the cytoplasmic and vacuolar ion concentrations or electrical potentials. The main potential drop in plant cells, however, appears to be at the plasmalemma rather than at the tonoplast (see Dainty, 1962; Findlay and Hope, 1964; Spanswick and Williams, 1964). Also, since the vacuole:cytoplasm ratio in *Gracilaria* is high, it is unlikely that moderate differences between the ion concentrations in the cytoplasm and vacuole would appreciably change the calculated $E - E_j$ values for these ions.

Finally, the large differences between the $C_i/C_o$ values for $K^+$, $Rb^+$ and $Cs^+$ (Table I) provide independent evidence for the involvement of an active process in the distribution of these ions. Otherwise the $C_i/C_o$ values for these ions would be similar, regardless of the membrane potential. Once again, the absence of selective intracellular ion binding is an important requirement (see Relman *et al.*, 1957).

The present results may be compared with MacRobbie and Dainty's (1958a) study of $Na^+$ and $K^+$ fluxes in the seaweed, *Rhodymenia*. Their findings of an active $Na^+$ efflux and active $K^+$ influx were similar to those presented here. One exception was their observation that light had only a small effect on $Na^+$ fluxes, suggesting that $Na^+$ transport was more closely related to respiration than to photosynthesis. Their light intensity, however, was about 25% of that used in the present study. As shown in Figure 3, $Na^+$ efflux decreased by a factor of about 0.65 when the light intensity was reduced from about 8500 lux to about 1000 lux. Also, as shown in Figures 1 and 3, the effects of light on ion movements might be obscured if the cells used for measuring fluxes in the dark were not previously adapted to darkness.

A stimulating effect of light on ion transport in plant cells has been reported often, although the mechanism of light stimulation is not clear (see Briggs, Hope and Robertson, 1961; Dainty, 1964). In *Nitella* it was recently suggested that active $K^+$ uptake is supported by light energy through the utilization of ATP produced in photophosphorylation, whereas active $Cl^-$ uptake is directly linked to light-driven electron-transfer reactions associated with oxygen evolution in photosynthesis (MacRobbie, 1965). The present observations on *Gracilaria* do little to clarify the way in which light promotes active ion fluxes (primarily $Na^+$ efflux and $K^+$ and $Cl^-$ influx). With respect to the cation fluxes, the stimulating effects of previous exposure to light were inhibited by anaerobiosis (Figs. 1 and 3). If these fluxes were ATP-dependent, however, and ATP was synthesized in the light, then one might expect that previous exposure to light would stimulate the fluxes in nitrogen as well as in air.

The variable effect of light on anion uptake was an unexpected finding. Chloride uptake was promoted by light, $Br^-$ uptake was only slightly affected, and $I^-$ uptake was depressed in the light (Fig. 2). In contrast, $Br^-$ uptake by *Nitella* was stimulated by light to a greater extent than was $Cl^-$ uptake (MacRobbie, 1962). The depressing effect of light on $I^-$ uptake was found to be even greater in three other seaweeds, *Ulva lactuca*, *Fucus vesiculosus* and *Hypnea musciformis*, than in *Gracilaria* (unpublished data). This appeared in every case to be due to a larger amount of bound $I^{131}$ in tissues which absorbed $I^{131}$ in the dark. Previous studies (see Shaw, 1962) suggest that in marine algae most of the intracellular iodine exists as iodide, although it may enter the cell in another form, thus raising doubts about the active transport of iodide, *per se*. Evidence from this and earlier studies, however, indicates that iodine is absorbed by an energy-dependent, if not, strictly speaking, an active transport process.

The passive ion fluxes, mainly $Na^+$ influx and $K^+$, $Rb^+$, $Cs^+$, $Cl^-$, $Br^-$, and $I^-$ efflux, were all stimulated by light (Figs. 2 and 4, Tables II and III). It is possible that light simply increased the passive permeability to the anions, since the rate coefficients for $Cl^-$, $Br^-$ and $I^-$ efflux were similar and their hydrated ion sizes are similar (see Briggs, Hope and Robertson, 1961). The mechanism of passive cation fluxes, however, may be different, *i.e.,* not simple diffusion. This is because the rate coefficients of efflux were in the order $K^+ > Rb^+ > Cs^+$, which is not consistent with predictions based on size or mobility of the hydrated ions (see Ussing, 1960; Briggs, Hope and Robertson, 1961). Thus an important part of the $K^+$ efflux in *Gracilaria* probably occurs by a mediated, but not active, process—possibly exchange diffusion. This argument may be extended to include $Na^+$, since the hydrated $Na^+$ ion is larger than $K^+$. A similar suggestion was made by MacRobbie and Dainty (1958a) for *Rhodymenia,* based on calculations of an unusually high energy requirement for supporting active $Na^+$ efflux. Their suggestion would be applicable also to $Na^+$ efflux in *Gracilaria.*

The ability of *Gracilaria* to maintain its high intracellular K:Na ratio in the absence of both light and oxygen is in contrast to many higher plant and animal cells, as well as some other marine algae. *Ulva lactuca* and *Fucus vesiculosus,* for example, were unable to maintain their normal high K:Na ratio under anaerobic conditions, losing over 50% of their intracellular $K^+$ in 24 hours (unpublished data). In *Fucus* the loss of $K^+$ was irreversible after 48 hours. Interestingly, both these seaweeds are highly resistant to extremes of temperature and dehydration (Kanwisher, 1957). *Porphyra* also has been found to lose $K^+$ and gain $Na^+$ when exposed to nitrogen (Eppley, 1958a).

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## SUMMARY

1. Distribution and transport of alkali and halide ions were studied in *Gracilaria foliifera,* a red marine alga. Ion concentrations, fluxes and rate coefficients were measured with radioisotopes and standard chemical techniques. The intracellular (vacuole) potential was measured with microcapillary electrodes and a high-impedance voltmeter.

2. Intracellular ion concentrations were estimated after correcting for 89% tissue water and 19% extracellular space. Intracellular concentrations of the major ions were (meq./kg. cell water): $Na^+$, 66; $K^+$, 680; $Cl^-$, 462. All of the

intracellular ions except $I^-$ appeared to be completely exchangeable and were probably in solution in the large cell vacuole.

3. Nernst equilibrium potentials, calculated for each ion under conditions of approximate flux equilibrium, were (mv.) : $Na^+$, +50; $K^+$, −105; $Rb^+$, −127; $Cs^+$, −85; $Cl^-$, −4; $Br^-$, −14; and $I^-$, +128. Comparison of these values with the measured vacuole potential of −81 mv. suggested active extrusion of $Na^+$ and active uptake of $K^+$, $Rb^+$, $Cl^-$ and $Br^-$. Cesium was in approximate electrochemical equilibrium, and the status of $I^-$ was uncertain due to some intracellular binding.

4. Cation fluxes were stimulated by light and, to a lesser extent, by exogenous substrate (glutamate). Previous exposure to light had a temporary stimulating effect on cation fluxes, provided oxygen was present. Anaerobiosis (nitrogen) depressed both influx and efflux of cations. Rate coefficients for the cation were in the order $Na^+ > K^+ > Rb^+, Cs^+$.

5. Anion fluxes were variably affected by light. Chloride uptake was promoted by light, $Br^-$ uptake was slightly stimulated, and $I^-$ uptake was depressed. Anion efflux, however, was consistently stimulated by light. Anaerobiosis inhibited the uptake of all anions. Rate coefficients for anion fluxes were similar to each other but were generally lower than the rate coefficients for cation fluxes.

6. With the exception of $I^-$, neither light nor anaerobiosis had much effect on the steady-state distribution of ions in *Gracilaria*. The intracellular $I^-$ concentration was much higher in the dark than in the light. This was also found in several other seaweeds, and appeared to be due to an increased amount of bound $I^-$ in non-photosynthesizing tissues.

## LITERATURE CITED

Barkely, R. A., and T. G. Thompson, 1960. The total iodine and iodate-iodine content of sea-water. *Deep-Sea Res.*, **7**: 24–34.

Bergquist, P. L., 1958. Evidence for separate mechanisms of sodium and potassium regulation in *Hormosira banksii*. *Physiol. Plant.*, **11**: 760–770.

Blinks, L. R., 1940. The relations of bioelectric phenomena to ionic permeability and to metabolism in large plant cells. *Cold Spring Harbor Symposia Quant. Biol.*, **8**: 204–215.

Blount, R. W., and B. H. Levedahl, 1960. Active sodium and chloride transport in the single celled marine alga *Halicystis ovalis*. *Acta Physiol. Scand.*, **49**: 1–9.

Briggs, G. E., A. B. Hope and R. N. Robertson, 1961. Electrolytes and Plant Cells. Blackwell Scientific Publications, Oxford, 217 pp.

Dainty, J., 1962. Ion transport and electrical potentials in plant cells. *Ann. Rev. Plant Physiol.*, **13**: 379–402.

Dainty, J., 1964. Physiological aspects of ion transport in plant cells and tissues. Pp. 41–52. *In:* J. F. Hoffman (ed.) The Cellular Functions of Membrane Transport. Prentice-Hall, Englewood Cliffs, New Jersey.

Eppley, R. W., 1958a. Sodium exclusion and potassium retention by the red marine alga, *Porphyra perforata*. *J. Gen. Physiol.*, **41**: 901–911.

Eppley, R. W., 1958b. Potassium-dependent sodium extrusion by cells of *Porphyra perforata*, a red marine alga. *J. Gen. Physiol.*, **42**: 281–288.

Eppley, R. W., 1959. Potassium accumulation and sodium efflux by *Porphyra perforata* tissues in lithium and magnesium sea water. *J. Gen. Physiol.*, **43**: 29–38.

Findlay, G. P., and A. B. Hope, 1964. Ionic relations of cells of *Chara australis*, VII. The separate electrical characteristics of the plasmalemma and tonoplast. *Australian J. Biol. Sci.*, **17**: 62–77.

Freundlich, H., 1926. Colloid and Capillary Chemistry (translated from the 3rd German edition by H. S. Hatfield). Methuen Co., London, 883 pp.

GUTKNECHT, J., 1965. Uptake and retention of $Cs^{137}$ and $Zn^{65}$ by seaweeds. *Limnol. Oceanogr.*, **10**: 58–66.

HOUSE, C. R., 1963. Osmotic regulation in the brackish water teleost, *Blennius pholis*. *J. Exp. Biol.*, **40**: 87–104.

KANWISHER, J., 1957. Freezing and drying in intertidal algae. *Biol. Bull.*, **113**: 275–285.

MACROBBIE, E. A. C., 1962. Ionic relations of *Nitella translucens*. *J. Gen. Physiol.*, **45**: 861–878.

MACROBBIE, E. A. C., 1965. The nature of the coupling between light energy and active ion transport in *Nitella translucens*. *Biochim. Biophys. Acta*, **94**: 64–73.

MACROBBIE, E. A. C., AND J. DAINTY, 1958a. Sodium and potassium distribution and transport in the seaweed *Rhodymenia palmata* (L.) Grev. *Physiol. Plant.*, **11**: 782–801.

MACROBBIE, E. A. C., AND J. DAINTY, 1958b. Ion transport in *Nitellopsis obtusa*. *J. Gen. Physiol.*, **42**: 335–353.

OSTERHOUT, W. J. V., 1940. Some models of protoplasmic surfaces. *Cold Spring Harbor Symposia Quant. Biol.*, **8**: 51–62.

RELMAN, A. S., A. T. LAMBIE, B. A. BURROWS AND A. M. ROY, 1957. Cation accumulation by muscle tissue: The displacement of potassium by rubidium and cesium in the living animal. *J. Clin. Invest.*, **36**: 1249–1256.

SCOTT, G. T., AND H. R. HAYWARD, 1954. Evidence for the presence of separate mechanisms regulating potassium and sodium distribution in *Ulva lactuca*. *J. Gen. Physiol.*, **37**: 601–620.

SCOTT, G. T., AND H. R. HAYWARD, 1955. Sodium and potassium regulation in *Ulva lactuca* and *Valonia macrophysa*. Pp. 35–64. *In:* A. M. Shanes (ed.) Electrolytes in Biological Systems. American Physiological Society, Washington, D. C.

SHAW, T. I., 1962. Halogens, pp. 247–253. *In:* R. A. Lewin (ed.) Physiology and Biochemistry of Algae. Academic Press, New York.

SHEPPARD, C. W., 1962. Basic Principles of the Tracer Method. John Wiley & Sons, New York, 282 pp.

SMALES, A. A., AND L. SALMON, 1955. Determination by radioactivation of small amounts of rubidium and caesium in sea-water and related materials of geochemical interest. *Analyst*, **80**: 37–50.

SPANSWICK, R. M., AND E. J. WILLIAMS, 1964. Electrical potentials and Na, K, and Cl concentrations in the vacuole and cytoplasm of *Nitella translucens*. *J. Exp. Bot.*, **15**: 193–200.

SUGAWARA, K., K. TERADA, S. KANAMORI, N. KANAMORI AND S. OKABE, 1962. On different distribution of calcium, strontium, iodine, arsenic and molybdenum in the northwestern Pacific, Indian and Antarctic Oceans. *J. Earth Sci., Nagoya Univ.*, **10**: 34–50.

USSING, H. H., 1960. The alkali metal ions in isolated systems and tissues. Pp. 1–195. *In:* O. Eichler and A. Farah (eds.) The Alkali Metal Ions in Biology. Springer-Verlag, Berlin.

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# Effect of Metallic Aluminum Particles on Oysters and Clams

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Chesapeake Science Vol. 6, No. 3, pp. 146–149 September, 1965

# Effect of Metallic Aluminum Particles on Oysters and Clams

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**ABSTRACT: The effect of powdered aluminum, used in photogrammetric studies of water currents, on the eastern oyster, *Crassostrea virginica*, and the soft-shell clam, *Mya arenaria*, was studied under laboratory conditions. Although the metal particles were removed by filtering activity of the organisms, no increase in aluminum was detected in the tissues and no increase was observed in water samples. These aquatic invertebrates apparently react to aluminum particles as they would to any other inorganic material in the same size range.**

## Introduction

Photogrammetric methods are frequently used for rapid yet accurate surveys of water currents in bays and harbors (Keller 1963). Essential to such studies is the selection of discrete targets that can be quickly and easily placed; that are inexpensive; and that will not present a hazard to navigation. Recently, fine particles of metallic aluminum have been found to meet these basic requirements and, in addition, when packaged properly can be rapidly seeded from low-flying aircraft over large surface areas with target size governed by the amount of packaged material. However, little is known of the possible effects of aluminum powder on aquatic organisms. Particular concern was expressed by State and industry for commercial species of mollusks in semi-enclosed bays and harbors where coalescing photo targets might produce toxic levels of aluminum powder.

The experiments described were conducted to evaluate the effect of fairly intense concentrations of particulate aluminum on adult soft-shell clams, *Mya arenaria*, and adult eastern oysters, *Crassostrea virginica*, by following the rate of uptake in molluscan tissues and change in ionic concentration in the milieu after various exposure periods.

Lt. Cmdr. Kelly E. Taggart, of the U. S. Coast and Geodetic Survey, brought the problem to my attention and made arrangements for the chemical analyses.

## Methods

Two plexiglass aquaria, holding about four cubic feet of water (113,268 cubic centimeters), were each fitted with a mercury thermometer, aerator, electric stirrer, and a water sampling siphon (Fig. 1). Sixteen adult soft-shell clams and 16 adult oysters were placed in each aquarium. One tank was maintained as a control while the other had one cubic centimeter of the powdered aluminum used in photogrammetry applied to the surface at the beginning of the experiment. Metallic powder, obtained from the Reynolds Metals Company, Richmond, Virginia, had a chemical composition of 97.5% flaked aluminum, 2.0% stearic acid, and 0.5% moisture. The particles were of a mean size of about 100 microns, and when applied at this rate of 1:113,268 (about $1:10^5$) were in greater concentrations than would be expected to occur under natural conditions where applications might range from $1:10^6$ to $1:10^9$.

Samples of water and molluscan tissues were obtained during the course of the experiment as indicated in Table 1, and observations on temperature, salinity, and syphoning activity were made daily in

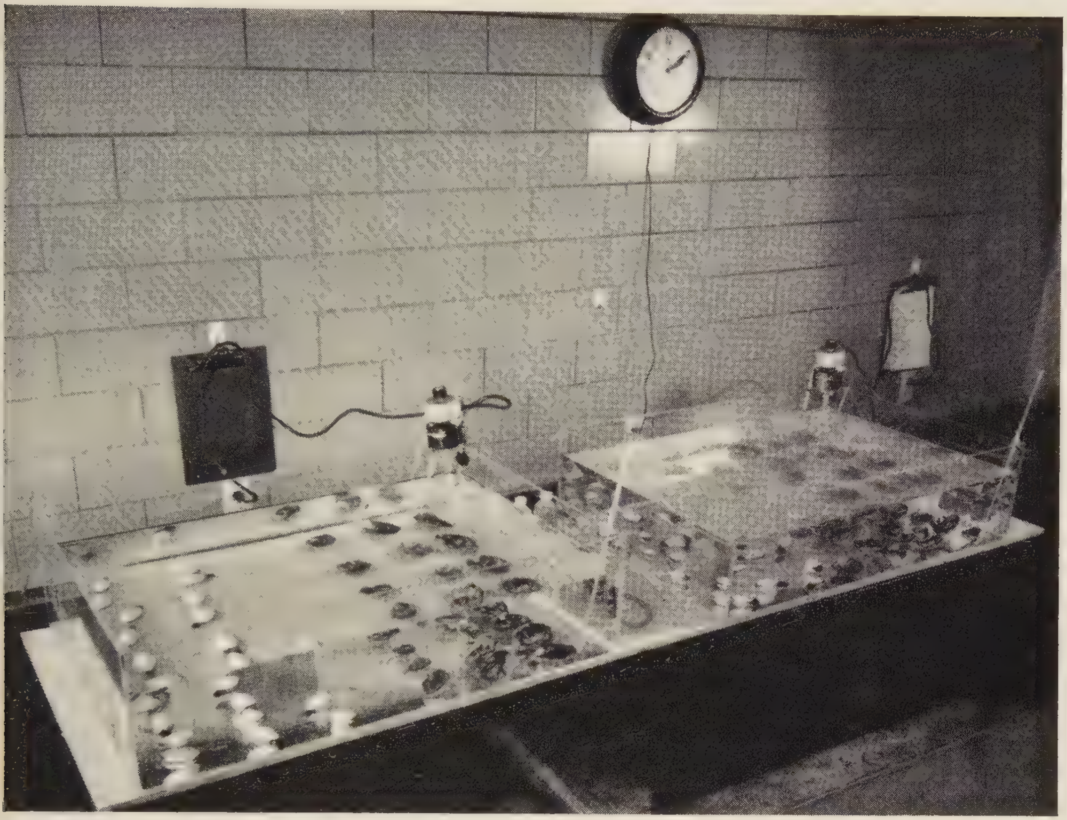

Fig. 1. Experimental aquaria used to expose selected bivalves to aluminum particles.

TABLE 1. Percent aluminum content in water samples and molluscan tissues.

| | Sample date | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | 5/7 | 5/8 | 5/11 | 5/12 | 5/14 | 5/18 | 5/20 | 5/22 | 5/25 |
| Water Sample | | | | | | | | | |
| Control | .007 | .007 | — | — | — | — | — | — | .007 |
| Experiment | .007 | .01 | .008 | .008 | .007 | .007 | .008 | .008 | .009 |
| Oyster Tissue | | | | | | | | | |
| Control | 0.6 | — | — | — | — | — | — | 0.1 | 0.1 |
| Experiment | — | 0.3 | — | — | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 |
| Clam Tissue | | | | | | | | | |
| Control | 0.6 | — | — | — | — | — | — | 0.09 | 0.1 |
| Experiment | — | — | — | 0.6 | — | 0.5 | 1.0 | 0.3 | 0.3 |

both tanks. Tissue samples were obtained by randomly selecting a clam or oyster, shucking out the body meats (only the visceral mass was taken from clams), and freezing at −72° C. in polyethylene bags.

Chemical analyses of water samples were made through the courtesy of the Water Quality Laboratory, U. S. Geological Survey, Washington, D. C., using the methods of Rainwater and Thatcher (1960). Spectrographic analyses of molluscan tissues were made with the cooperation of the U. S. Bureau of Mines, College Park, Maryland. Ashed tissue samples were diluted 1:1 and 1:9. A direct current arc was then used to excite 25 milligram charges of each dilution and the spectra were recorded photographically. Visual estimates of the aluminum content were made by comparing the degree of blackening of selected aluminum lines in the samples with the same aluminum lines in a graded series of standards.

Salinities in both aquaria were in the range of 9 to 10‰, temperature varied from 17.2° C. to 23.4° C., and pH from 7.1 to 7.4 during the experimental period.

## Results

All animals, both experimental and control, survived for the entire two-week test period. Within the first 24 hours the aluminum particles had penetrated the surface film, had been thoroughly mixed with the water, and had been filtered by the molluscs to be deposited as fecal pellets or as pseudo feces. Gross and microscopic observation of tissues revealed no discoloration in any of the sample animals although aluminum particles were observed within the mantle cavity, on the gills, and on the palps. Aluminum particles were observed in one clam at the internal base of the siphons on the seventh day of the experiment. All animals appeared to siphon normally and responded to external stimuli rapidly and with appropriate response.

At least two epifaunal invertebrates were introduced with the oysters. They were the anemone, *Aiptasia pallida,* and a small polychaete, *Nereis succinea.* Both organisms apparently were unaffected by the aluminum, although the anemone may have ingested particles.

The results of chemical analyses are summarized in Table 1. The aluminum content of control water samples did not change during the entire experiment, while water from the experimental tank fluctuated within a range of 0.3 ppm. Such fluctuation did not indicate a general increase in soluble aluminum, however, and can be ascribed to analytical accuracy. The tissue samples were reduced to ash, equal to about 1% original wet tissue weight, and examined by spectrographic analysis, giving results accurate within 0.5 to 2 times the true value. Aluminum content of oyster tissues was less variable than in clam tissue, perhaps reflecting the uniform size of the oysters. Clam tissues were somewhat more variable, but no increasing trend, indicating aluminum uptake, could be discerned. The high level of 1.0%, obtained on May 20, resulted from the analysis of an entire clam, less shell. The rough periostracum, especially that covering the long siphons, could have trapped aluminum particles in the folds.

## Discussion and Conclusions

The concentration of aluminum in sea water at 19‰ chlorinity, has been reported as 0.01 ppm. (Goldberg 1963); 0.05 ppm. (Vinogradov 1953); and 0.5 ppm. (Sverdrup, Johnson, and Fleming 1942). Though few data are available on the aluminum content of invertebrates, the average value for molluscan tissues is said to be in the range of .01% to .001% by weight of dry matter (Vinogradov 1953).

The levels of aluminum found in water samples from this experiment (0.7 to 1.0 ppm) were somewhat higher than those reported above. However, water used in the experiment was taken from an inshore estuarine environment where quantities of colloidal clay particles, containing a large percentage of aluminum, may be found in suspension. These colloidal particles may also have contributed to the elevated quantities in the tissues from the experimental animals. Of course, the important point here is that there was no significant trend during the experiment indicating uptake by the organisms, nor an increase in the soluble aluminum content of the water. Apparently, these pelecypods reflect the aluminum concentrations in their environment and are not actively concentrating the metal.

Particulate aluminum in the aquatic environment may be incorporated into at least two discrete pathways. First, the material will be dispersed within the water mass after a maximum period of 24 hours; much sooner if there is considerable surface activity. These particles will eventually settle, depending on turbulence and other physical factors in the water body, and become mixed with the bottom sediments. The second pathway involves concentration of dispersed particles by living organisms. In the case of adult oysters and soft-shell clams, the particles are removed in the normal filtering and feeding activities of the organism. They are wrapped in mucus, and may pass through the gut to be deposited as fecal pellets or, more frequently, are rejected and deposited as pseudo feces where the aluminum is again mixed with the bottom sediments. Ingestion of aluminum particles by other aquatic organisms could produce adverse effects, either by upsetting chemical balances or by mechanical clogging of respiratory and feeding activities, but the information provided by this study indicates that: 1. in inshore environments dissolved aluminum may be present at relatively high concentration; 2. particulate aluminum applied to surface layers in the aquatic environment is dispersed in bottom sediments within a relatively brief period of time; 3. no significant increases were noted in the aquatic medium, indicating that this metallic aluminum is rapidly oxidized and is relatively insoluble; 4. tissue levels of aluminum in adult clams and oysters were always much higher than water levels but probably fluctuate with the concentrations in the environment; and 5. some aquatic invertebrate animals respond to aluminum particles as they would to other material of the same size range.

## LITERATURE CITED

Goldberg, E. D. 1963. The oceans as a chemical system. *Section I, Chapter I, In The Sea, Vol. 2., M. M. Hill, editor, Interscience Publishers, N. Y.* 554 pp.

Keller, M. 1963. Tidal current surveys by photogrammetric methods. *U. S. Dept. Commerce, Coast & Geodetic Survey Tech. Bull. No.* 22. 20 pp.

Rainwater, F. H. and L. L. Thatcher. 1960. Methods for collection and analysis of water samples. *U. S. Dept. Interior, Geological Survey Water-Supply Paper* 1454. 301 pp.

Sverdrup, H. U., M. W. Johnson and R. H. Fleming. 1942. The Oceans—Their Physics, Chemistry and General Biology. *Prentice Hall, Inc., N. J.* 1087 pp.

Vinogradov, A. P. 1953. The Elementary Chemical Composition of Marine Organisms. *Sears Foundation for Marine Research, Memoir No.* 2. *Trans. by J. Efrom and J. Setlow. Sears Foundation for Mar. Res., Yale Univ. New Haven, Conn.* 647 pp.

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# Limnetic Cottid Larvae and Their Utilization as Food by Juvenile Sockeye Salmon

## INTRODUCTION

Freshwater cottids, lacking a swim bladder, are usually benthic fishes. This paper presents data on the planktonic occurrence of larvae of *Cottus aleuticus* in limnetic areas (open water) of Brooks Lake and on the ultilization of cottid larvae as food by juvenile sockeye salmon (*Oncorhynchus nerka*). Brooks Lake is one of four lakes that serve as important rearing areas for juvenile salmon in the Naknek system.

The term larvae as used in this paper refers to small fish that have absorbed the yolk but have not assumed the general appearance of adults.

Most records of cottid–salmon relations deal with the predatory activity of cottids upon salmon eggs, alevins, or fry. Ricker (1941) found the prickly sculpin (*C. asper*) to be a predator of juvenile sockeye salmon in Cultus Lake. Hunter (1959) reported on predation of pink salmon (*O. gorbuscha*) and chum salmon (*O. keta*) by *C. asper* and *C. aleuticus*. Patten (1962) found the torrent sculpin (*C. rhotheus*) and the reticulate sculpin (*C. perplexus*) to be predators on coho salmon fry (*O. kisutch*). Pritchard (1936), Robertson (1949), and others have also discussed cottid predation on young salmon.

Records of salmon predation on cottids are scarce. Foerster (1925) found a partly decomposed 15-millimeter cottid in the stomach of an 85-millimeter migrating yearling sockeye salmon. Ricker (1937) reported 51 larval cottids from the stomach of a 138-millimeter sockeye salmon. Merrell (1964) reported that juvenile sockeye salmon from Brooks Lake in 1957 contained cottid larvae.

No previous North American literature that specifically discusses the planktonic occurrence of freshwater cottids could be found, although such might be inferred from the above accounts of sockeye salmon predation on cottid larvae. In recent laboratory experiments Krejsa (unpublished) has demonstrated that larvae of *C. aleuticus* and *C. asper* are planktonic upon hatching and, in the case of *C. asper* at least, remain so for approximately 5 weeks. He reports that two larval *Cottus* spp. in the University of British Columbia fish collection were taken by an unknown collector in a plankton tow over 1,000 feet (328 m) of water in Owikeno Lake, British Columbia. Northcote and Hartman (1959) reported unusual behavior in *C. asper* in Nicola Lake, British Columbia. The cottids were moving in a stream or band alongshore where most of them were swimming at or near the surface; those farther offshore were near the bottom. While this is not true limnetic occurrence, it illustrates that cottids are not confined to the bottom.

## METHODS

The equipment used to sample cottids and other species included 1-meter- and 3.1-meter-diameter nets towed behind two outboard skiffs (Johnson, 1956, and Burgner[1]), small otter trawls towed behind a single skiff (Baldwin, 1961), and seines of varying dimensions. After cottid larvae were found in the stomachs of sockeye salmon, a 1-meter tow net with 1.6-millimeter-mesh cod liners was used to capture larvae.

Routine sampling of fish in the Brooks Lake area since 1957 has documented the occurrence of both *C. aleuticus* and *C. cognatus* in streams around the lake and in the lake itself. *Cottus aleuticus* is the most abundant form in streams[2] and is apparently confined to shallower waters of the lake, while *C. cognatus* is most abundant in the lake and occurs at all depths. This is a reversal of the ecological distribution of *C. aleuticus* reported by Ricker (1960) who found that *C. aleuticus* was limited to bathybenthic areas of Cultus Lake. The Cultus Lake population, however, is apparently a dwarfed "ecological relict," and Ricker points out that in neighboring populations *C. aleuticus* is commonly found in streams.

### OCCURRENCE OF LIMNETIC COTTID LARVAE

Forty-nine yearlings and 11 young-of-the-year sockeye salmon were captured in a tow net in Brooks Lake between 2230 and 2400 hours on 28 July 1963. The sampling tract, which was in midlake, was about 3 km long and was oriented along the main axis of the lake. Water depths were in excess of 66 m, and all fish were taken in the top 6.1 m. No cottid larvae occurred in stomachs of young-of-the-year sockeye salmon, but stomachs of 21 (45 per cent) of the yearling fish contained small larval fishes that were identified as *Cottus* spp. The number of cottids per stomach in those containing larvae ranged from 1 to 27 and averaged 5.8. The larvae accounted for most of the food in stomachs containing them, and represented 39 per cent of the total volume in the stomachs of all yearling salmon. Other food items represented were copepods, cladocerans, and dipterans. Stomachs of other sockeye salmon caught with tow nets in the same area on 9 July, 26 August, 5 and 9 September 1963, did not contain cottid larvae.

Eighteen planktonic cottid larvae were caught along the same sampling tract with a 1-meter tow net on 9 August 1963 at 2300 hours. These larvae, which were all caught in a single tow that sampled the surface meter of water, ranged from 8 to 13 mm and averaged 11.6 mm in total length. Four earlier tows, between 2200 and 2300 hours of the same day, yielded no cottid larvae. Surface water temperature was 10 C. Sixteen of these larvae were identified as *C. aleuticus*. The two smallest specimens (8 and 10 mm long) could not be identified to species. Two daylight surface tows with the 1-meter net in the same area on 13 August yielded a 12-millimeter *C. aleuticus* larvae. Five additional *C. aleuticus* were caught during night tows, two specimens each on 19 and 22 August with the 1-meter net and one specimen on 26 August with the 3.1-meter net. These specimens ranged from 11 to 17 mm and averaged 13.8 mm in total length.

In 1961, 21 *C. aleuticus* were caught in 3.1-meter tow nets in limnetic areas of Brooks Lake between 11 August and 1 September. In 1962, 17 cottids, which were not identified to species, were caught in tow nets between 17 August and 5 September. No lengths are available for any of these cottids, although few if any could have been less than 17 mm long because of the mesh size in the cod end of the nets.

### DISCUSSION

Although *C. cognatus* is the most abundant cottid in Brooks Lake, all of the identifiable larvae from limnetic catches have been *C. aleuticus*. Because they were partially digested the small larvae from the sockeye salmon stomachs could not be identified to species. Samples of *C. aleuticus* larvae captured later in the same limnetic areas suggest that the unidentified small larvae in the salmon stomachs were also *C. aleuticus*.

Limnetic *C. aleuticus* larvae in Brooks Lake may originate from either shoal areas in the lake or inlet streams or both. Krejsa (unpublished) believes that planktonic larvae in *C.*

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[1] Burgner, R. L. (1959) Study of population density and competition between populations of young red salmon and sticklebacks. Fisheries Research Institute, Univ. Washington. 15 p.

[2] Hartman, Wilbur L. (1960) Red Salmon Studies, Field Operations Report, 1959, Brooks Lake Laboratory. Bureau of Commercial Fisheries Alaska Region, 88 p.

*aleuticus* and *C. asper* are correlated with larger numbers of small eggs, and that in cottids with fewer large eggs, such as *C. cognatus*, planktonic larvae would be unlikely. This follows the general concept that species with small numbers of large eggs would be less likely to have life history stages with heavy mortalities (i.e., planktonic larvae) than species with great numbers of small eggs.

The duration of limnetic life for species of cottids with planktonic larvae apparently extends beyond the larval stage. In late August and early September, limnetic catches in Brooks Lake involve cottids at least 17 mm in total length. Three of the four known cases of juvenile sockeye salmon predation on cottids occurred in July and specifically involved larvae. Ricker's record (1937) from Cultus Lake was on 4 July and the present account was on 28 July. A reexamination of data collected at Brooks Lake in 1957 and summarized by Merrell (1964) indicated that two yearling sockeye salmon caught on 13 July had 17 and 22 "yolk fry cottids" in their stomachs. Each of these three accounts involved planktonic cottid larvae that could have been *C. aleuticus*. The utilization of larvae of planktonic cottids as food by juvenile sockeye salmon illustrates the complexity of predation problems, which can be reciprocal with two species each feeding on the young of the other.

## ACKNOWLEDGMENTS

Mr. Richard Krejsa has freely given me the benefit of his thinking and research on limnetic cottid larvae. He also made many helpful comments on the manuscript and confirmed the tentative identification of *C. aleuticus* larvae from Brooks Lake.

## LITERATURE CITED

Baldwin, W. J. 1961. Construction and operation of a small boat trawling apparatus. California Fish Game 47(1): 87–95.

Foerster, R. E. 1925. Studies in the ecology of sockeye salmon (*Oncorhynchus nerka*). Contrib. to Canadian Biology New Series 2(16): 335 422.

Hunter, J. G. 1959. Survival and production of pink and chum salmon in a coastal stream. J. Fish. Res. Bd. Canada 16(6): 835–886.

Johnson, W. E. 1956. On the distribution of young sockeye salmon (*Oncorhynchus nerka*) in Babine and Nilkitkwa Lakes, B. C. J. Fish. Res. Bd. Canada 13(5): 695–708.

Merrell, T. R., Jr. 1964. Ecological studies of sockeye salmon and related limnological and climatological investigations, Brooks Lake, Alaska, 1957. U. S. Fish Wildl. Serv., Spec. Sci. Rep. Fish. 456: 1–66.

Northcote, T. G., and G. F. Hartman. 1959. A case of "schooling" behavior in the prickly sculpin, *Cottus asper* Richardson. Copeia 1959(2): 156–158.

Patten, Benjamin G. 1962. Cottid predation upon salmon fry in a Washington stream. Trans. Amer. Fish. Soc. 91(4): 427–429.

Pritchard, A. L. 1936. Stomach content analysis of fishes preying upon the young of Pacific salmon during the fry migration at McClinton Creek, Masset Inlet, British Columbia. Canadian Field-Naturalist 50(6): 104–105.

Ricker, W. E. 1937. The food and the food supply of sockeye salmon (*Oncorhynchus nerka* Walbaum) in Cultus Lake, British Columbia. J. Biol. Bd. Canada 3(5): 450–468.

——. 1941. The consumption of young sockeye salmon by predaceous fish. J. Fish. Res. Bd. Canada 5(3): 293–313.

——. 1960. A population of dwarf coastrange sculpins (*Cottus aleuticus*). J. Fish. Res. Bd. Canada 17(6): 929–932.

Robertson, J. G. 1949. Sockeye fry production in a small British Columbia Coastal Watershed. Fish. Res. Bd. Canada, Prog. Rep. Pacific Coast Sta. 80: 55 57.

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# Homogeneity of Age-Length Frequencies Among Months and Quarters of the Year for Haddock Caught on Georges Bank, 1962

BY R. C. HENNEMUTH

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International Commission for the Northwest Atlantic Fisheries
Research Bulletin Number 2, 1965.

# Homogeneity of Age-Length Frequencies Among Months and Quarters of the Year for Haddock Caught on Georges Bank, 1962

This study of samples of age-length frequencies of haddock landings from Georges Bank, 1962, was undertaken to determine the degree of homogeneity among months and quarters within the calendar year. This is of some interest because of the economies in collection, analysis, and publication which can be achieved by condensation of sample age-length data.

The age-frequencies were aggregated by 5-cm length intervals, because expected values for the standard 2-cm intervals were, on the average, too low for valid analysis. The frequencies of the younger and older age groups within a given 5-cm interval were combined for the same reason, when expected values were less than five.

## Among Months Within Quarters of Year

The expected age-frequency for each month within the quarter,

$$E_{ij} = (\sum_i 0_{ij}\ \sum_j \sum_i 0_{ij})\ (\sum_j 0_{ij}), \text{ where}$$

$0_{ij}$ = number of fish observed in the $i^{th}$ month of age $j$,

$i = 1, 2, 3$ months,
$j = 1, 2, \ldots, m$ ages.

Noting that $\sum_i O_{ij} = \sum_i E_{ij}$, as required, the index of dispersion (Hoel, 1954) for each month,

$$\chi^2_i = \sum_j ( (O_{ij} - E_{ij})^2\ E_{ij}),$$

with $m$-1 degrees of freedom.

The data and calculations are summarized by quarters in Table 1. There were five quarters, out of 32 tested, for which the $\chi^2$ index was significant. Four of the five were associated with large deviations within the 2 and 3 year age groups.

TABLE 1. Analysis of homogeneity of age distributions of haddock caught on Georges Bank in 1962 by 5-cm intervals

| Length class cm | Age range | D.F. | $\chi^2$ values Months within quarter 1 | 2 | 3 | 4 | Months within year |
|---|---|---|---|---|---|---|---|
| 35–39 | 2–3 | 3 | 2.89 | 4.60 | 1.06 | 1.67 | 34.32[a] |
| 40–44 | 2–4 | 6 | 4.90 | 31.30[a] | 12.72[a] | 6.84 | 187.02[a] |
| 45–49 | 2–5 | 9 | 6.95 | 3.32 | 21.28[a] | 11.38 | 141.35[a] |
| 50–54 | 3–6 | 9 | 3.60 | 6.85 | 11.24 | 15.29 | 185.49[a] |
| 55–59 | 3–7 | 12 | 10.38 | 21.72[a] | 3.99 | 25.90[a] | 193.52[a] |
| 60–64 | 4–8 | 12 | 5.86 | 12.73 | 5.43 | 3.49 | 121.97[a] |
| 65–69 | 6–8 | 6 | 5.22 | 5.64 | 4.84 | 6.90 | 25.31 |
| 70–74 | 7–9+ | 6 | 2.67 | 3.34 | 3.67 | 7.30 | 13.84 |

[a] Indicates probability $(\chi^2) < .05$

## Among Months Within the Year

Using the above procedure with $i = 1, 2, \ldots, 12$ months, the dispersion among months within the year was calculated (Table 1, last column).

The indices for six of the eight length groups were significant, the two nonsignificant indices being in the two largest length groups.

## Conclusion

The rather low incidence of heterogeneity found among months within quarters, indicates that recruitment of age-groups is gradual and that aggregating age-length frequencies by quarters of the years would not form biased age-length keys. The large amount of heterogeneity among months within the year precludes annual aggregation for purposes of estimating age composition of catch, unless, of course, proportional sampling was employed.

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### References

HOEL, PAUL G. 1954. Introduction to Mathematical Statistics, 2nd. Ed., Wiley and Sons, New York, 331 p.

# ATLANTIC MENHADEN . . . A MOST ABUNDANT FISH

The Atlantic Menhaden (*Brevoortia tyrannus*) is a herringlike fish commonly called mossbunker, bunker, pogy, fatback, and frequently (but incorrectly) alewife or shad. It ranges from New England to Florida and is one of the most abundant fishes found along the coast.

## A Truly Industrial Fish

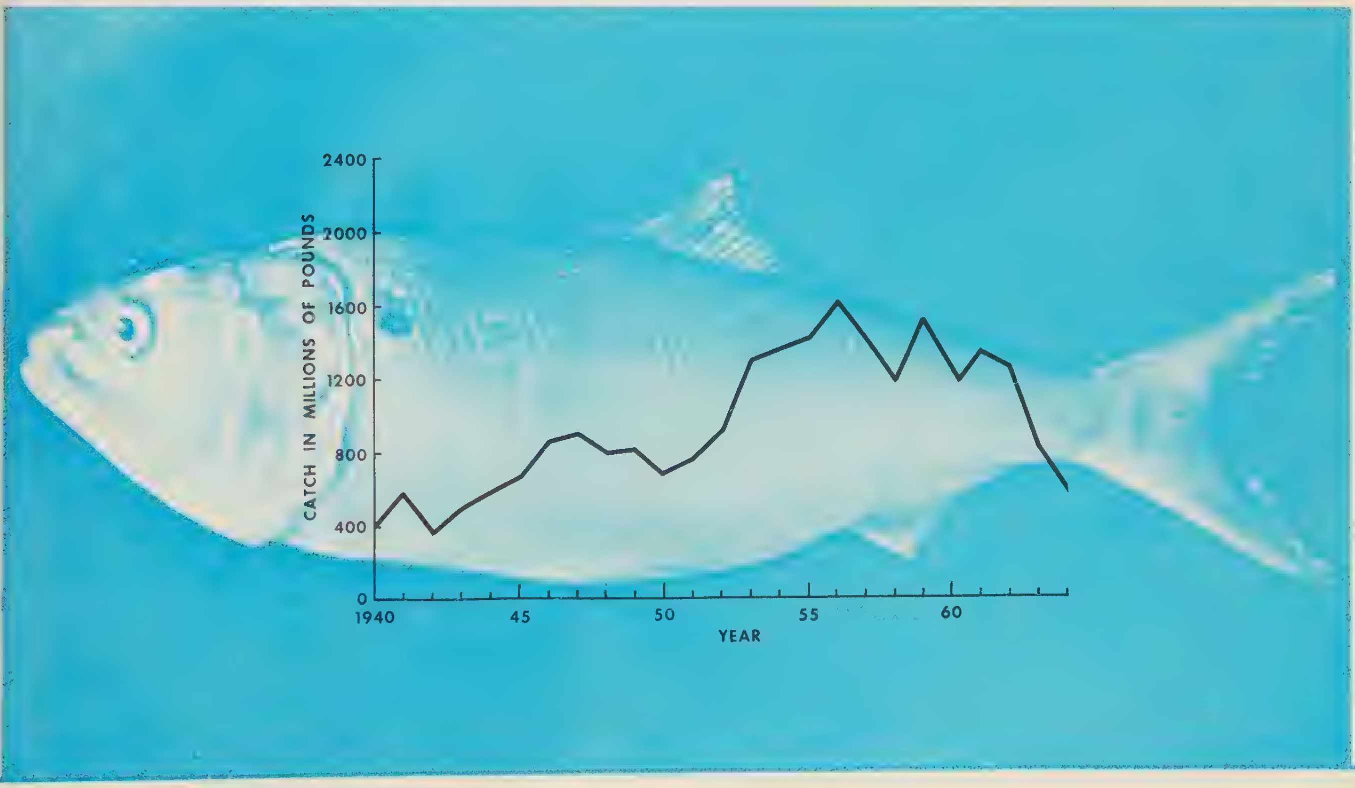
The Menhaden is not normally used for direct consumption; its catches are processed into meal, oil, and condensed solubles. The meal is rich in protein and makes an excellent food supplement for poultry, hogs, mink, and other animals. The oil is used in various commercial products including paints, soaps, and lubricants.

## Menhaden Top All Other Fish

U.S. fishermen catch more pounds of Menhaden each year than any other species. Landings for the Atlantic coast reached a record high in 1956 of about 1.6 billion pounds, valued at about $20 million. In 1963 the catch began to decline drastically. Prior to 1963 most of the U.S. catch was made on the Atlantic coast, but now more Menhaden (chiefly *B. patronus*, the Gulf Menhaden) are caught in the Gulf of Mexico.

## Fishery Is Modernized

Menhaden normally occur in dense schools and are caught mostly with purse seines. The carrier vessels are fairly large; most range from 100 to 200 feet long. Each

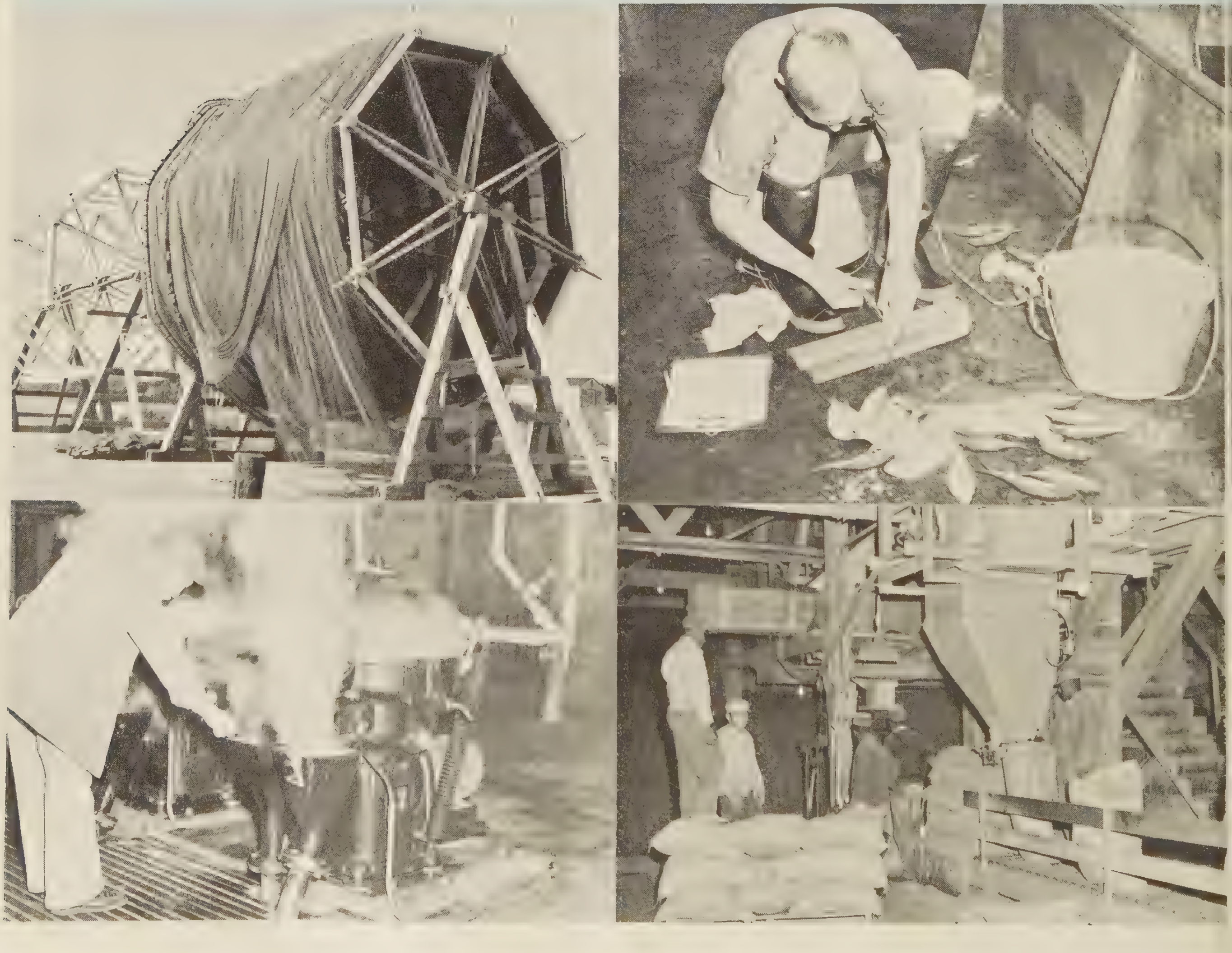


MARINE RESOURCES OF THE ATLANTIC COAST

Leaflet Number 2, October 1965

ATLANTIC STATES MARINE FISHERIES COMMISSION, 336 East College Avenue, Tallahassee, Florida 32301

After a successful set, crewmen pull in the purse seine net while the striker boatman in the dory maintains his close watch on the encircled school of menhaden and the carrier vessel hoves to until most of the net is boated (top). After each voyage the hugh seines are washed, reeled, and left to dry (middle left). Biologists obtain size measurements, scales, stomach contents, and other information from samples of the catch (middle right). One of the steps in oil processing is centrifugation (lower left). After the fish meal has been dried it is bagged for shipment (lower right).



an carry from 125 to over 350 tons of fish. Fishing ntails the use of two 36-foot seine boats that are carried o the fishing grounds on the carrier vessel. The purse eine, about 200 fathoms long and 10 fathoms deep, is placed aboard the two smaller boats, half in each boat. ncreased fleet efficiency has been accomplished in ecent years by using airplanes, which spot schools of Menhaden and direct the setting of the nets by radioelephone. The seine boats, circling the school in opposite directions, let out the net to surround the fish. The bottom of the net is then closed, or pursed, and its sides pulled into the boats with hydraulic blocks until the catch is concentrated. The carrier vessel then pumps the catch into its hold.

## Fishing Is Seasonal

In addition to a fishery that usually lasts from May to October, along the Atlantic coast, there is a fall fishery off North Carolina from November to January. Fishing normally is confined to relatively shallow water near the coast.

## Population Changes Are Important

In recent years, the very large 1958 year class has been the main support of the Atlantic fishery; however, these fish no longer are present in large numbers, and since 1961 the percentage of younger fish in the catch has increased greatly. The older fish, which helped to stabilize violent fluctuations in the catch resulting from variations in the strength of year classes, no longer are present in significant numbers. Production from the present fishery, which relies principally on young fish, will be more sensitive to fluctuations in year-class strength.

## Is There Overfishing?

Increased fishing and the recent decline in the Atlantic Menhaden catches have raised questions of overfishing and the need for possible management. Current research is aimed at providing the information needed to answer these questions, as well as to identify the interrelations of various stocks believed to exist in the different fishing areas. Many different fishing regulations are now in effect along the coast, and local or State agencies should be contacted for details.

## From Ocean To Estuary And Return

Atlantic Menhaden spawn in the ocean over the Continental Shelf. Most spawning apparently takes place off North Carolina during December, January, and February, but some also occurs from Massachusetts to New Jersey during May to October and from Delaware to Florida during November to March. An individual female may spawn from 40,000 to 700,000 eggs, depending on the size of the fish. After fertilization, the eggs float near the surface and hatch in about 2 days. The larvae enter the estuarine nursery areas when they are nearly 1 inch long and eventually move into the tributaries near the upper limits of salt water where they transform from slender, transparent individuals into deep-bodied juveniles resembling adult Menhaden. From time of entry early in the year until autumn, when seasonal chilling of the water apparently causes a general exodus, about 8 months are spent in the shallow, inshore nursery areas. Some juveniles may overwinter in the sounds and bays along the south Atlantic coast, particularly during mild winters. Yearlings and adults usually are associated with nearshore waters but may appear in certain bays and lower estuaries.

## Feeding Habits Change

When they metamorphose into juveniles, larval Menhaden undergo extensive changes particularly in their feeding and digestive structures. The larvae feed selectively on individual, planktonic animals, whereas the juveniles and adults, whose gill arches support a basketlike sieve capable of retaining very small organisms, are non-selective feeders that obtain food by swimming with mouths gaped, filtering minute plants and animals from the water.

## Do They Migrate?

Atlantic Menhaden, at least the older fish, appear to migrate seasonally along the coast — northward in the spring and southward in the fall. It is not known if the stocks south of Cape Hatteras, N.C., also migrate in this manner.

### Life Is Hazardous

Predation and parasitism are apparent, but their effects on the Menhaden resource are not known. Menhaden are preyed upon by many other fishes as well as by marine mammals and birds. Bluefish, mackerels, sharks, porpoises, and other carnivores often are seen near Menhaden schools. The Menhaden is infected with various internal and external parasites. The more conspicuous are the copepod crustacean which attaches itself and forms egg cases that stream along the side or back of the fish, and the isopod crustacean that attaches itself inside the fish's mouth, thus giving rise to a local name "bugfish" for Menhaden.

A number of environmental factors may affect the Menhaden resource. Extremely low winter water temperatures or pollution may cause heavy mortalities of larvae and juveniles in the estuaries. Also, conditions in the ocean such as water temperature, salinity, and food may influence the distribution, movement, and even the success of spawning.

### Old Fish In North

The age composition of Atlantic Menhaden in the commercial catch varies in the different fishing areas. Young-of-the-year fish are relatively unimportant commercially. In the Atlantic fishery, 1- and 2-year-olds now make up the bulk of the catch. Individuals over 2 years old are caught mainly in the more northern waters and in the fall off North Carolina.

### Growth Is Fast

Atlantic Menhaden grow rapidly during the first 3 years of life. On the average, fish in the catch weigh about a half pound as 1-year-olds, nearly a pound as 3-year-olds, and then grow less each year until reaching about 1½ pounds as 9-year-olds.

### Research Is Intensive

The Bureau of Commercial Fisheries has been studying Atlantic Menhaden since 1955. This program is headquartered at the Biological Laboratory in Beaufort, N.C., and concerns: (1) the main features of Menhaden life history, (2) the causes of fluctuations in Menhaden abundance and the development of techniques for predicting these fluctuations, and (3) the population characteristics (e.g., growth and mortality) needed to assess condition of the stocks and to make proper decisions regarding the intensity of their harvesting. A large-scale tagging experiment to obtain vital statistics of the Menhaden resource is about to begin.

The Virginia Institute of Marine Science at Gloucester Point, Va., has studied Menhaden for many years. Their work is principally concerned with the eggs, larval, and juvenile stages in Chesapeake Bay and the nearby ocean.

The Bears Bluff Laboratories at Wadmalaw Island, S.C., incidental to work on shrimp, have also collected data for several years on the abundance of larval and juvenile Menhaden in that area.

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# EFFECTS OF SYNTHETIC SURFACTANTS ON THE LARVAE OF CLAMS (*M. MERCENARIA*) AND OYSTERS (*C. VIRGINICA*)

*Herbert Hidu*

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# EFFECTS OF SYNTHETIC SURFACTANTS ON THE LARVAE OF CLAMS (*M. MERCENARIA*) AND OYSTERS (*C. VIRGINICA*)

*Herbert Hidu*

The replacement of natural soap products by synthetic detergents and the development of other synthetic surfactants since World War II have been very rapid. Including the surfactants used in industry and those used in household detergents, 3.5 bil lb (1.6 bil kg) of synthetic surfactants are used annually. This represents 90 percent of all detergents produced in 1962 (1).

Present methods of wastewater treatment are ineffective in breaking down the surfactant portions of certain of the syndets and these persist for long periods in effluent waters (1) (2). This, understandably, causes concern about the possible effect of these chemicals on aquatic animals. In larger rivers, where the water is subject to repeated use along its course, the persistency of these surfactants poses a particular problem.

The effects of syndets on various freshwater organisms have been the subject of numerous investigations (2) (3) (4). There has been, however, little investigation of their effects on estuarine and marine animals living in close proximity to the outflow of large rivers. Of special concern are the effects on populations of clams and oysters since commercial shellfisheries are particularly dependent on brackish river-mouth systems for reproduction of these species.

In the studies reported here, toxic concentrations of eight surfactant compounds on the larvae of clams (*Mercenaria mercenaria*) and oysters (*Crassostrea virginica*) have been determined. Active surfactant compounds rather than commercially marketed products were used in these studies because the various inactive carriers or "builders" added to the active components of marketed detergents have been shown to be relatively non-toxic to other aquatic animals (2).

Samples of the three general types of surfactants, the anionics, cationics, and nonionics, were tested. Of the three groups the anionic compounds are the most important because they comprise the bulk of surfactant likely to be found in wastewater (1). Within the anionic group three alkyl aryl sulfonate compounds, labeled ABS-1, ABS-2, and ABS-3, and one alkyl sulfate, AS-1, were tested. Two samples of each of the less important cationic, C-1, C-2, and nonionic, N-1, N-2, surfactants were tested. The chemical composition of all test compounds is listed in Table VII.

## Methods

Standard methods of culturing bivalve larvae have been followed throughout the present series of experiments. The methods of spawning have been described in detail by Loosanoff and Davis (5) and Davis (6);

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those of rearing larvae, by Davis and Guillard (7) and Davis (8).

To evaluate properly the effect of surfactants on the rapidly developing larvae of bivalve mollusks two separate tests were utilized. First, the effect of various concentrations of the compounds on the development of the fertilized egg into normal free-swimming larvae was determined. Second, using normal two-day-old veliger larvae, the effects of surfactants on survival and growth during the free-swimming larval stage were determined, normally about a two-week period prior to setting. This is necessary because a given compound will often affect one of the early developmental stages at quite different concentrations from those which will affect adversely later stages. For example, a concentration of toxicant that is harmless to a fully-developed veliger larva may be toxic to a fertilized egg in early cleavage stages. The reverse of this situation also often is true.

Thus, surfactants were tested with duplicate cultures of newly fertilized eggs which were set up at each test concentration of the surfactant along with four untreated control cultures. A modified geometric series of test concentrations was used throughout, i.e., 0.25, 0.50, 1.00, 2.50, 5.00, and 10.00 mg/l. Cultures were of 1-l volume in glass beakers with equal numbers of fertilized eggs (generally 20,000 to 30,000/l) in each culture vessel. Temperatures were held at 24°C ± 1° and ultraviolet-treated seawater was used throughout. Prior to u.v. treatment water was filtered with orlon filters designed to remove particles larger than 15 $\mu$. Cultures of developing embryos were sampled using aliquots at 4/250 of total volume 48 hr after fertilization of the eggs, by which time they are normally fully-developed veliger larvae. The number of normal straight-hinge veligers present in each culture was determined by a total count of the sample.

Numbers of normal larvae developing in each of the duplicate cultures at each concentration were averaged, as were the numbers obtained in each of four control cultures. Results then were expressed as a percentage ($R$) of survival in control cultures (Table I) and were calculated as follows:

$$R = \frac{\text{Mean number of larvae in experimental cultures}}{\text{Mean number of larvae in control cultures}} \times 100$$

In a similar manner the effects of surfactants on survival and growth of fully-developed, two-day straight-hinge larvae were determined. In these tests 10,000 to 15,000 larvae reared to the 2-day straight-hinge larval stage under normal conditions were used in each 1-l culture. Both seawater and test compound were renewed every second day with larvae being retained on a stainless-steel screen. In this way buildup of harmful metabolites was minimized and the desired concentration of the test compound more nearly was maintained throughout the test period. Cultures were fed a mixture of live flagellate algal food generally at a rate of 0.01 ml of packed cell volume per 1-l culture per day (7). The cultures were continued in this manner until the clam larvae were 12 days old (10 days of continuous exposure) or until the oyster larvae were 14 days old (12 days of continuous exposure to the test chemicals), by which time many of the larvae in control cultures had reached setting size.

Regardless of the size of larvae cultures were sampled quantitatively at the end of the 10-day period for clams and the 12-day period for oysters. The effect of treatment on survival was determined as in the two-day experiments and expressed again as a

TABLE I.—Percentage Fertilized Egg Development at Different Syndet Concentrations

| Concentrations, Gross Product (mg/l) | Anionic | | | | | | | | Cationic | | | | Nonionic | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Alkyl Aryl Sulfonates | | | | | | Alkyl Sulfate | | C-1, 100-% Active | | C-2, 100-% Active | | N-1, 100-% Active | | N-2, 100-% Active | |
| | AAS-1, ? Active | | AAS-2, 54.8-% Active | | AAS-3, 60-% Active | | AS-1, 27–31.4-% Active | | | | | | | | | |
| | C | O | C | O | C | O | C | O | C | O | C | O | C | O | C | O |
| 0.0025 | | | | | | | | | | | 109 | 110 | | | | |
| 0.005 | | | | | | | | | | | 85 | 111 | | | | |
| 0.01 | | | | | | | | | | | 35* | 94 | | | | |
| 0.025 | | | | | | | 92 | 95 | | 101 | 0 | 95 | | | | |
| 0.05 | | | 92 | 118 | | | 80 | 112 | | 114 | 0 | 101 | | | | |
| 0.10 | | | 83 | 114 | | 92 | 89 | 119 | | 116 | 0 | 43* | | 85 | | |
| 0.25 | | 94 | 93 | 98† | | 91† | 89 | 93 | 99 | 80† | | 8 | | 95 | | |
| 0.50 | | 91 | 100 | 47* | 95 | 72 | 95† | 98 | 96 | 49* | | | 99 | 82† | 92 | 90 |
| 1.00 | 100 | 86* | 97† | 0 | 90† | 0* | 79 | 62* | 61* | 1 | | | 7* | 38* | 105 | 83 |
| 2.50 | 68† | 0 | 0* | | 3* | 0 | 8* | 0 | 0 | | | | 0 | 0 | 0* | 0* |
| 5.00 | 60 | | | | 0 | 0 | 0 | 0 | 0 | | | | 0 | 0 | 0 | 0 |
| 10.00 | 0* | | | | 0 | | 0 | 0 | 0 | | | | 0 | 0 | 0 | 0 |

Note: C = clams; O = oysters. Relative percentage, *R*, indicates those eggs developing into normal 48-hr straight-hinge larvae. Results are listed as composite figures for all replicate experiments.

* Indicates significant reductions (95-percent level) from controls in all replicate experiments.

† Indicates significant reductions (95-percent level) from controls in one but not all replicate experiments.

percentage, *R*, of those surviving in control cultures (Table II).

In addition to measurement of survival, effect of treatment on larval growth was determined in the 10- and 12-day experiments. This was necessary since, in most cases, larval growth is retarded or stopped at concentrations of test compounds lower than those which will directly kill larvae. Any reduction in larval growth is detrimental since it would retard time of setting, thus increasing chances of loss of larvae in the field through predation, disease, and dispersion.

Effect of treatment on larval growth was determined by measuring length of the larvae, parallel to the hinge line, in the 10- and 12-day samples. Fifty clam larvae or 100 oyster larvae

TABLE II.—Larvae Survival in Different Syndet Concentrations

| Concentrations, Gross Product (mg/l) | Anionic | | | | | | | | Cationic | | | | Nonionic | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Alkyl Aryl Sulfonates | | | | | | Alkyl Sulfate | | C-1, 100 % Active | | C-2, 100-% Active | | N-1, 100-% Active | | N-2, 100-% Active | |
| | AAS-1, Active | | AAS-2, 54.8-% Active | | AAS-3, 60-% Active | | AS-1, 27–31.4-% Active | | | | | | | | | |
| | C | O | C | O | C | O | C | O | C | O | C | O | C | O | C | O |
| 0.0025 | | | | | | | | | | | | | | | | |
| 0.005 | | | | | | | | | | | | 103 | | | | |
| 0.01 | | | | | | | | | | | 90 | 98 | | | | |
| 0.025 | | | | | | | | | 97 | 103 | 79 | 145 | | | | |
| 0.05 | | | 88 | 129 | | | | | 95 | 101 | 103 | 122 | | | | |
| 0.10 | | | 95 | 98 | | 95 | | | 97 | 98† | 77 | 55 | | 116 | | |
| 0.25 | | 85 | 93 | 95 | | 87 | | | 82† | 83 | 40* | 0* | | 97† | | |
| 0.50 | | 86 | 95 | 80† | 96 | 103† | | 108 | 59* | 54* | 29 | | 97 | 88 | 99 | 99 |
| 1.00 | 113 | 82† | 97 | 21* | 100 | 76 | | 100 | | | 0 | | 91 | 71 | 96 | 89† |
| 2.50 | 116 | 75 | 63† | 0 | 88† | 0* | 96 | 91 | | | | | 27* | 0* | 88 | 1* |
| 5.00 | 112 | | | | 0* | 0 | 68* | 19* | | | | | 0 | | 0* | 0 |
| 10.00 | 86† | | | | 0 | 0 | 3 | 7 | | | | | 0 | | 0 | 0 |

Note: C = clams; O = oysters; Relative percentage, *R*, indicates O larvae surviving from the 2nd to 14th day and C larvae surviving from the 2nd to 12th day. Results are listed as composite figures for all replicate experiments.

* Indicates significant reductions (95-percent level) from controls in all experiments.

† Indicates significant reductions (95-percent level) from controls in one but not all replicate experiments.

from each sample were measured. The highly kurtotic nature of the frequency distributions of clam larval measurements permitted good accuracy with the lesser number of measurements. Growth in test cultures again was expressed as a percentage of growth obtained in untreated control cultures (Table III) and was calculated as follows:

$$G = \frac{\text{Mean length of larvae in experimental culture} - \text{mean length at 2 days}}{\text{Mean length of larvae in control culture} - \text{mean length at 2 days}} \times 100$$

At least two separate experiments were run to test the effects of each compound on each species of larvae. The minimum concentration of the compound causing a statistically significant reduction in survival or growth of the larvae was determined. Since the mean length and number of larvae surviving were determined for each of four separate control cultures, it was possible to calculate a standard error ($S\ \bar{x}$) for growth and for survival of the overall means for the control cultures. Counts of survivors or mean lengths, in test cultures, that were reduced by more than 1.96 standard errors of the mean for the four control cultures, were deemed significantly different from the controls at the 95-percent confidence level (9).

The minimum concentrations of test materials giving a significant reduction in growth or in survival in replicate experiments are shown in Tables I, II, and III. Also noted are lower concentrations of test materials that gave a significant reduction in some but not all replicate experiments. The apparent discrepancies in these data are discussed in the section on results.

## Results

For purposes of clarification and discussion, Tables I, II, and III (which list all growth and survival figures) have been condensed in Tables IV, V, and VI. Tables IV, V, and VI list concentrations of surfactants in terms of mg/l of active ingredients instead of gross product as in Tables I, II, and III. This, of course, makes the assumption that the fillers or "builders"

**TABLE III.—Larvae Growth in Different Syndet Concentrations**

| Concentrations, Gross Product (mg/l) | Anionic | | | | | | | | Cationic | | | | Nonionic | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Alkyl Aryl Sulfonates | | | | | | Alkyl Sulfate | | | | | | | | | |
| | AAS-1, ? Active | | AAS-2, 54.8-% Active | | AAS-3, 60-% Active | | AS-1, 27–31.4-% Active | | C-1, 100-% Active | | C-2, 100-% Active | | N-1, 100-% Active | | N-2, 100-% Active | |
| | C | O | C | O | C | O | C | O | C | O | C | O | C | O | C | O |
| 0.0025 | | | | | | | | | | | | | | | | |
| 0.005 | | | | | | | | | | | | 97 | | | | |
| 0.01 | | | | | | | | | | | 102 | 102 | | | | |
| 0.025 | | | | | | | | | 99 | 103 | 107 | 87 | | | | |
| 0.05 | | | 103 | | | | | | 90 | 93† | 89* | 74* | | | | |
| 0.10 | | | 102 | 91 | | 94 | | | 85† | 69* | 74 | 32 | | 108 | | |
| 0.25 | | 81 | 101 | 70* | | 103 | | | 43* | 44 | 53 | 0 | | 100 | | |
| 0.50 | | 101† | 98† | 37 | 101 | 97† | | | 13 | 30 | 40 | | 113 | 92† | 107 | 105 |
| 1.00 | 99 | 75* | 89* | 0 | 99 | 55 | | | 3 | 4 | 6 | | 105 | 68* | 108 | 74† |
| 2.50 | 101 | 45 | 24 | 0 | 53* | 0* | 98 | 100 | 0 | | | | 61* | 0 | 85* | 0* |
| 5.00 | 92* | | | | 0 | 0 | 70* | 17* | 0 | | | | 0 | 0 | 0 | 0 |
| 10.00 | 25 | | | | 0 | 0 | 32 | 6 | 0 | | | | 0 | 0 | 0 | 0 |

Note: C = clams; O = oysters. Growth, *G*, is expressed as the percentage increase in mean length relative to that of control, for O larvae from the 2nd to 14th day and C larvae from the 2nd to 12th day. Results are listed as composite figures for all replicate experiments.

* Indicates significant reductions (95-percent level) from controls in all replicate experiments.

† Indicates significant reductions (95-percent level) from controls in one but not all replicate experiments.

TABLE IV.—Syndet Concentrations Affecting Larvae Development, Growth, and Survival

| Type and Trade Name | Survival to 2 Days | | Survival from 2 to 12 and 14 Days | | Growth from 2 to 12 and 14 Days | |
|---|---|---|---|---|---|---|
| | Clams | Oysters | Clams | Oysters | Clams | Oysters |
| Anionic | | | | | | |
| Alkyl aryl sulfonates | | | | | | |
| 1. AAS-1* | 10.00 (2.50) | 1.00 | 25.00 (10.00) | >2.50 (1.00) | 5.00 | 1.00 (0.50) |
| 2. AAS-2 | 1.37 (0.55) | 0.27 (0.14) | >1.37 ( 1.37) | 0.55 (0.27) | 0.55 (0.27) | 0.14 |
| 3. AAS-3 | 1.50 (0.60) | 0.60 (0.15) | 3.00 ( 1.50) | 1.50 (0.30) | 1.50 | 1.50 (0.30) |
| Alkyl sulfates | | | | | | |
| 4. AS-1 | .73 (0.15) | 0.29 | 1.46 | 1.46 | 1.46 | 1.46 |
| Cationic | | | | | | |
| 5. C-1 | 1.00 | 0.50 (0.25) | 0.50 ( 0.25) | 0.50 (0.10) | 0.25 (0.10) | 0.10 (0.05) |
| 6. C-2 | 0.01 | 0.10 | 0.25 | 0.25 | 0.05 | 0.05 |
| Nonionic | | | | | | |
| 7. N-1 | 1.00 | 1.00 (0.50) | 2.50 | 2.50 (0.25) | 2.50 | 1.00 (0.50) |
| 8. N-2 | 2.50 | 2.50 (0.50) | 5.00 | 2.50 (1.00) | 2.50 | 2.50 (1.00) |

* Expressed as mg/l gross product.

Note: Minimum concentrations (in mg/l active ingredient) of surfactants giving a significant reduction in numbers of fertilized eggs developing into normal straight-hinge larvae and of growth and survival of larvae from the 2nd to 12th day (clams) and 14th day (oysters). Values given are the lowest concentrations tested that gave significant reductions in all experiments. Values in parenthesis indicate concentrations that gave significant reductions in some but not all replicate experiments.

used in the products are not harmful to the test animals. All surfactants which were not 100-percent active contained water as the major inactive ingredient except AAS-2 in which the major inactive ingredient was sodium sulfate ($Na_2SO_4$) (see Table VII). Since Henderson (2) showed that $Na_2SO_4$ was toxic to freshwater fish only at very high levels (9,000 to 14,000 mg/l), it is assumed here that $Na_2SO_4$ is non-toxic to larvae at the relatively low test concentrations.

There was some disagreement between consecutive experiments using a given compound in the minimum test concentrations which reduced significantly larval growth and survival from that in control cultures (Table IV). Entries listed as double figures indicate that significant reduction came at different test concentrations between replicate experiments. When such disagreement took place, however, it was generally only plus or minus one test concentration interval.

Variation of this type, even in controlled laboratory experiments, indi-

TABLE V.—Mean Concentrations Affecting Larvae Growth and Survival

| Type | Concentration (mg/l Active Ingredient) | | | | | |
|---|---|---|---|---|---|---|
| | Clams | | Oysters | | Both Species | |
| | Mean | Range | Mean | Range | Mean | Range |
| Anionic | | | | | | |
| Alkyl aryl sulfonate* | 1.55 | 0.55–3.00 | 0.76 | 0.14–1.50 | 1.15 | 0.14–3.00 |
| Alkyl sulfate | 1.22 | 0.73–1.46 | 1.07 | 0.29–1.46 | 1.15 | 0.29–1.46 |
| Cationic | 0.34 | 0.01–1.00 | 0.25 | 0.05–0.50 | 0.30 | 0.01–1.00 |
| Nonionic | 2.66 | 1.00–5.00 | 2.00 | 1.00–2.50 | 2.33 | 1.00–5.00 |
| For all surfactants | 1.44 | 0.01–5.00 | 1.02 | 0.05–2.50 | 1.23 | 0.01–5.00 |

* AAS-1 not entered in these figures.

Note: Means were compiled by averaging lowest concentrations of all compounds tested that significantly reduced, in all replicate experiments, survival of developing embryos and growth and survival of developed veliger larvae (From Table IV).

cates that small differences in environmental conditions between experiments are apparently enough to alter the effect of these compounds on bivalve larvae. The primary source of uncontrolled variability was in the filtered, natural seawater used in the experiments. The seawater was pumped automatically at given incoming tide levels; therefore, it is of comparatively uniform salinity. There is, however, apparently enough change in the chemical and biotic constituents from experiment to experiment and from season to season to cause some variation in experimental results.

Care must be taken, then, not to use laboratory experimental values indiscriminately under widely-variant field conditions. For example, it would be presumptuous to state that under all field conditions 1.0 mg/l of the nonionic surfactant, N-1, would be harmful to developing clam embryos or that 0.50 mg/l, under all conditions, would be harmless although the laboratory experiments seemed to indicate this. These figures are more important, rather, in establishing ranges of concentration which, if approached under field conditions, are likely to cause direct harm to pelecypod larvae. To determine whether a borderline concentration of surfactant in the field caused harm to molluscan populations would require, of course, specific bioassay of the water itself and an evaluation of the effect of other external environmental factors.

TABLE VI.—Concentrations of Syndets Affecting a 50-Percent Reduction in Larvae Development

| Test Compound | Active Ingredient (mg/l) | |
|---|---|---|
| | Clams | Oysters |
| Anionic | | |
| Alkyl aryl sulfonate | | |
| AAS-1* | 5.83 | 1.63 |
| AAS-2 | 0.94 | 0.27 |
| AAS-3 | 1.03 | 0.39 |
| Alkyl sulfate | | |
| AS-1 | 0.47 | 0.37 |
| Cationic | | |
| C-1 | 1.27 | 0.49 |
| C-2 | 0.0085 | 0.09 |
| Nonionic | | |
| N-1 | 0.77 | 0.86 |
| N-2 | 1.75 | 1.60 |

* Expressed as mg/l gross product (percentage active ingredient unavailable).

Note: These concentrations produced a 50-percent reduction in the percentage of fertilized clam and oyster eggs developing to normal 48-hr straight-hinge larvae. These values are comparable to 48-hr $TL_m$ values of acute toxicity studies.

TABLE VII.—Chemical Composition (as Available) of All Tested Surfactants

| Product | Composition |
|---|---|
| Anionic<br>Alkyl aryl sulfonates | |
| AAS-1 | active<br>alkyl naphthalene sulfonate<br>polyphosphate<br>fatty alcohol sulfates<br>inactive<br>not available<br>(percentages not available) |
| AAS-2 | active<br>alkyl benzene sulfonate 54.8%<br>inactive<br>$Na_2SO_4$ 40.3%<br>Free oil 0.5%<br>NaOH 1.3%<br>$Na_2CO_3$ 0.7%<br>$H_2O$ 2.6% |
| AAS-3 | active<br>triethanolamine dodecyl benzene sulfonate 60%<br>inactive<br>$H_2O$ 40% |
| Alkyl sulfate | |
| AS-1 | active<br>alkyl sulfate 26.0 to 28.9%<br>Free fatty alcohol 1.0 to 2.5%<br>inactive<br>(probably $H_2O$) 68.6 to 73% |
| Cationic | |
| C-1 | active<br>para diisobutyl phenoxyethoxy ethyl dimethyl benzyl ammonium chloride monohydrate 98.8%<br>inactive<br>$H_2O$ 1.2% |
| C-2 | active<br>lauryl pyridinium chloride 100% |
| Nonionic | |
| N-1 | active<br>iso-octyl phenoxy polyethoxy ethanol 100% |
| N-2 | active<br>alkyl polyether alcohol 100% |

Both clam and oyster larvae showed a relatively low tolerance to all of the surfactants tested (Table V). The range of minimum concentrations of active ingredients, which gave significant reductions in growth or survival in replicate experiments for both clams and oysters, was from 0.01 to only 5.00 mg/l with a mean concentration for all compounds of only 1.23 mg/l.

Some differences in toxicity were noted for the major groups of surfactants, i.e., nonionic, cationic, and anionic, although these differences were relatively small. Compounds within each of the major groups generally exhibited approximately the same degree of toxicity (Table IV). As a group the cationic surfactants were the most toxic with a mean minimum concentration causing significant reductions in growth and survival to clams and oysters of 0.30 mg/l (Table V). The two groups of anionic compounds, the alkyl aryl sulfonates and the alkyl sulfates, were intermediate in toxicity with mean concentrations of 1.15 mg/l causing significant reductions. The nonionics, as a group, were least toxic, but a mean concentration of 2.33 mg/l was sufficient to reduce growth and survival of larvae.

In general, oyster larvae were harmed by lower concentrations of surfactants than were clam larvae. The mean concentration of all surfactants reducing significantly oyster growth and survival was 1.02 mg/l, whereas that for clams was 1.44 mg/l (Table V). The surfactants are not unique in this respect. In most of the other tolerance studies comparing larvae of the two species, oyster larvae have been more susceptible to toxins. This was shown in previous studies of the effects of pesticides on larvae (8). A notable exception to this relationship in the present study, however, was the effect of C-2 (lauryl pyridinium chloride) on the development of fertilized eggs of clams and oysters (Table I). It required 10 times as much lauryl pyridinium chloride (0.10 mg/l) to reduce significantly the percentage of oyster embryos developing normally as was required to produce a similar reduction in the percentage of clam embryos developing normally (0.01 mg/l). This relationship was revealed in many trials and appears to be the actual effect of freshly mixed stock solution of the compound.

Growth of clam and oyster larvae, in most cases, was hindered by lower test concentrations than those which caused appreciable mortality in the 10- and 12-day experiments (Table IV). This again has been observed in previous studies (8) and is what one might logically expect at marginally toxic concentrations of any material. A marked reduction in the rate of growth of larvae may be as harmful as direct mortality, since any significant lengthening of the larval period increases chances for loss through other means.

The fertilized eggs of clams and oysters were, in general, killed at lower concentrations of surfactant than those which caused mortality in the fully developed veliger larvae (Table IV). Only one surfactant (C-1) allowed normal development of eggs at concentrations higher than those producing significant mortality in fully-formed larvae. Mortality of fully-developed larvae was measured after 10- or 12-days' exposure, whereas mortality of fertilized eggs was measured after only 48-hr exposure. In no case were fully-developed veliger larvae killed within 48 hr at as low a concentration of the test compounds as those which caused mortality in the developing embryos.

The measurement of mortality, or prevention of development, of fertilized eggs then, at least in the case of surfactants tested here, may be used as a measure of acute toxicity. Forty-eight-hour median tolerance limit ($TL_m$) values thus have been interpolated from effects of surfactants on survival of developing eggs only (Table VI). The only purpose of these

$TL_m$ values is to permit comparison of these data more directly with acute toxicity studies in other animals. In many instances considerably lower concentrations were harmful to larvae in other ways.

## Discussion

Published data on concentrations of surfactants found in estuarine habitat of oysters and clams are extremely limited. The State of Maryland (10), however, has measured as high as 0.06 mg/l of ABS in the mouth of the St. Mary's River, an important oyster-seed-producing area. Surfactant content of many fresh water systems has been measured and published (2) (11) and it is possible that concentrations are maintained to a large degree at the mouths of rivers that in many cases form important shellfish-producing areas. The concentration of syndets in the Ohio River at Wheeling, West Virginia, was reported as high as 12.0 mg/l with a maximum daily average of 4.0 mg/l, and the concentration of "detergent" in British rivers has been reported to range from 0.20 to 4.9 mg/l (2). Concentrations of surfactants detrimental to bivalve larvae (0.01 to 5.0 mg/l), therefore, coincide very closely with those which may be expected in certain natural waters inhabited by shellfish.

Probably of equal importance are concentrations of surfactants too low in themselves to cause direct harm to larvae. In combination with low levels of other pollutants, however, they may become very detrimental indeed. The possibility of such combined detrimental effect was considered important in the marine pollution situation by Galtsoff (12). Should such a situation exist, it would be very difficult to pinpoint specific causes of mortality since the concentration of each pollutant would be too low, acting independently, to be harmful to eggs and larvae of bivalves.

The laboratory experiments have shown that surfactants, at concentrations below those which might be encountered in the marine habitat, are detrimental to clam and oyster larvae. This situation might very well have a serious effect in certain areas of commercial production of these species. It is important, therefore, that determinations be made of the amount of surfactant present in important marine and brackish water areas inhabited by shellfish. It is suggested that laboratory experiments reported here be augmented by suitable bioassays which would take into account the wide variation of accompanying ecological factors encountered in nature.

## Summary

The results of these experiments on the effect of eight synthetic surfactive agents on clam and oyster larvae indicate the following:

1. Development of fertilized eggs and growth and survival of fully-formed veliger larvae of clams and oysters was reduced by concentrations of surfactants between 0.01 and 5.00 mg/l of active ingredient, depending on the surfactant used. The mean concentration producing such a reduction was 1.23 mg/l;

2. The cationic surfactants, lauryl pyridinium chloride (C-2) and a quarternary ammonium compound (C-1), were the most toxic. The mean of the minimum concentrations causing a significant reduction in development of fertilized eggs and survival and growth of veliger larvae was 0.30 mg/l. The range of minimum test concentrations causing these reductions was 0.01 to 1.00 mg/l;

3. The anionic surfactants, three alkyl aryl sulfonates (AAS-1, AAS-2, and AAS-3) and one alkyl sulfate (AS-1), were intermediate in toxicity. The mean minimum concentration causing a reduction in growth and sur-

vival was 1.15 mg/l and the range was 0.14 to 3.00 mg/l;

4. The nonionic surfactants, two alkyl polyether alcohols (N-1 and N-2), were least toxic. The mean minimum concentration causing a reduction in growth and survival was 2.33 mg/l and the range was 1.00 to 5.00 mg/l;

5. Clam larvae were less sensitive to surfactants than were oyster larvae. The mean minimum concentration for all detergents required to reduce significantly growth and survival of clam larvae was 1.44 mg/l, while that for oyster larvae was 1.02 mg/l;

6. Reduction in the rate of growth of larvae of clams and oysters occurred at lower concentrations, in most cases, than those required to produce mortality. In acute toxicity tests development of fertilized eggs was always halted at lower surfactant concentrations than those producing mortality of fully-formed veliger larvae within 48 hr; and

7. Concentrations of surfactant detrimental to clam and oyster larvae may be reached in certain commercial shellfish habitats. This study should be augmented by determination of surfactant levels encountered over shellfish beds. Bioassay methods could be used to determine possible modification of the effect of these compounds by the widely variant ecological factors found in nature.

## Acknowledgments

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## References

1. Sisley, J. P., and Wood, D. J., ''Encyclopedia of Surface-Active Agents.'' Chemical Publishing Co., New York, N. Y. (1952).
2. Henderson, C., Pickering, Q. H., and Cohen, J. M., ''The Toxicity of Synthetic Detergents and Soaps to Fish.'' *Sewage and Industrial Wastes*, **31**, 3, 295 (Mar. 1959).
3. Herbert, D. W. M., Elkins, G. H. J., Mann, H. T., and Hemens, J., ''The Toxicity of Synthetic Detergents to Rainbow Trout.'' *Water and Waste Trt. Jour.* (Brit.), 6, 394 (1957).
4. Mann, H., ''The Action of Surface Active Washing Agents on Fish and Animals Forming Fish Food.'' *Arch. Fischwiss.* (Germany), 6, 131 (1955); *Water Poll. Abs.* (Brit.), 28, 393 (1955).
5. Loosanoff, V. L., and Davis, H. C., ''Conditioning *V. mercenaria* for Spawning in Winter and Breeding its Larvae in the Laboratory.'' *Biol. Bull.*, **98**, 1, 60 (1950).
6. Davis, H. C., ''On Food and Feeding of Larvae of the American Oyster, *C. virginica*.'' *Biol. Bull.*, **104**, 3, 334 (1953).
7. Davis, H. C., and Guillard, R. R., ''Relative Value of Ten Genera of Microorganisms as Foods for Oyster and Clam Larvae.'' *U. S. Fish and Wildlife Serv., Fishery Bull. 136*, 8, 293 (1958).
8. Davis, H. C., ''Effects of Some Pesticides on Eggs and Larvae of Oysters, *C. virginica*, and Clams, *V. mercenaria*.'' *Comm. Fish. Rev.*, **23**, 12, 8 (Dec. 1961).
9. Arkin, H., and Colton, R. R., ''Statistical Methods.'' Barnes & Noble, Inc., New York (1958).
10. Maryland, State of, ''St. Mary's River Water Quality 1962.'' Unpublished report, Md. Water Pollution Control Comm., Annapolis, Md. (1963).
11. ''Synthetic Detergents in Perspective.'' Technical Advisory Council, Soap and Detergent Association, 295 Madison Ave., New York 17, N. Y. (1962).
12. Galtsoff, P. S., ''Environmental Requirements of Oysters in Relation to Pollution.'' *Trans. 2nd Seminar Biol. Probs. Water Poll.*, Tech. Rept. W60-3, R. A. Taft San. Eng. Center, Cincinnati, Ohio, 128 (1959).

# DISTRIBUTION AND ABUNDANCE OF THE POLYCHAETE, *MANAYUNKIA SPECIOSA* LEIDY, IN WESTERN LAKE ERIE[1]

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## ABSTRACT

The abundance and distribution of the freshwater polychaete, *Manayunkia speciosa*, in 1961, are described for western Lake Erie. Previous records reveal that the species has either been generally overlooked or presently its numbers have greatly increased in the area considered.

Although annelids of the class Polychaeta live predominantly in marine and brackish environments, a few species occur in fresh water. One freshwater species, *Manayunkia speciosa* Leidy, was first discovered in the Schuylkill River, Pennsylvania, by Joseph Leidy (1858), and first reported from the Great Lakes (Duluth, Minnesota, harbor, western Lake Superior) by Meehean (1929). Individuals of this genus were later collected and described from Lake Erie, east of the Bass Islands, by Krecker (1939). He believed them to be specifically different from the worms found previously in the United States, and proposed the name *M. eriensis*. Additional specimens were recorded from this general area by Pettibone (1953), who, following the interpretation of Hartman (1951), considered them to be *M. speciosa* and relegated *M. eriensis* to synonomy. Through personal communication with Dr. N. Wilson Britt, I have learned that he recorded this species from western Lake Erie in 1954.

*M. speciosa* was found from Lake Erie again in 1961, when personnel of the U.S. Bureau of Commercial Fisheries collected samples for a study of the benthos of the extreme western end of the lake. This species was found in many of the samples—often in great numbers (fig. 1). It was most abundant at a station in the mouth of the Detroit River where one station yielded an average of 45,292 per square meter. One sample with a Petersen dredge (approximate area of 1/14 m$^2$) contained more than 6,530 worms. Such abundance is in sharp contrast to findings in the earlier studies. Pettibone (1953) reported "Some 23 specimens. . . ."; Krecker (1939) found a single specimen originally and "additional specimens" later; and Wright (1955) reported no polychaetes in his 1928–30 study of the bottom fauna of western Lake Erie and the mouth of the Detroit River. Wright's study and the 1961 survey by the Bureau of Commercial Fisheries covered the same area and had many stations in common. To wash the bottom samples, Wright used even smaller mesh screening materials (0.5 mm) than were used in the 1961 study (*ca.* 0.65 mm, U.S. Standard No. 30). Wright is of the opinion (personal communication) that a few individuals could have been overlooked because of the low magnification used in sorting his samples, but that it is unlikely that the worms would have escaped notice if they had been abundant.

The distribution and frequency of occurrence of *M. speciosa* in western Lake Erie apparently is influenced by the Detroit River and its outflow. The species was not found off the mouth of the Maumee River. This wide variation in population density may be due to differences in sediment type, nature of the currents, water quality, or other factors. Although organic substances are known to favor the occurrence of certain marine polychaetes (Reish, 1960), the possible

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effect of the concentration of organic materials in the Detroit River on the distribution of this freshwater species in western Lake Erie is not known.

The distribution of *M. speciosa* extends also to certain connecting waters of the Great Lakes. I have found numbers of them in bottom samples from Lake St. Clair and from the St. Marys River. A sample taken in central Lake St. Clair revealed 195 specimens. A few dozen were found in a sample from St. Marys River.

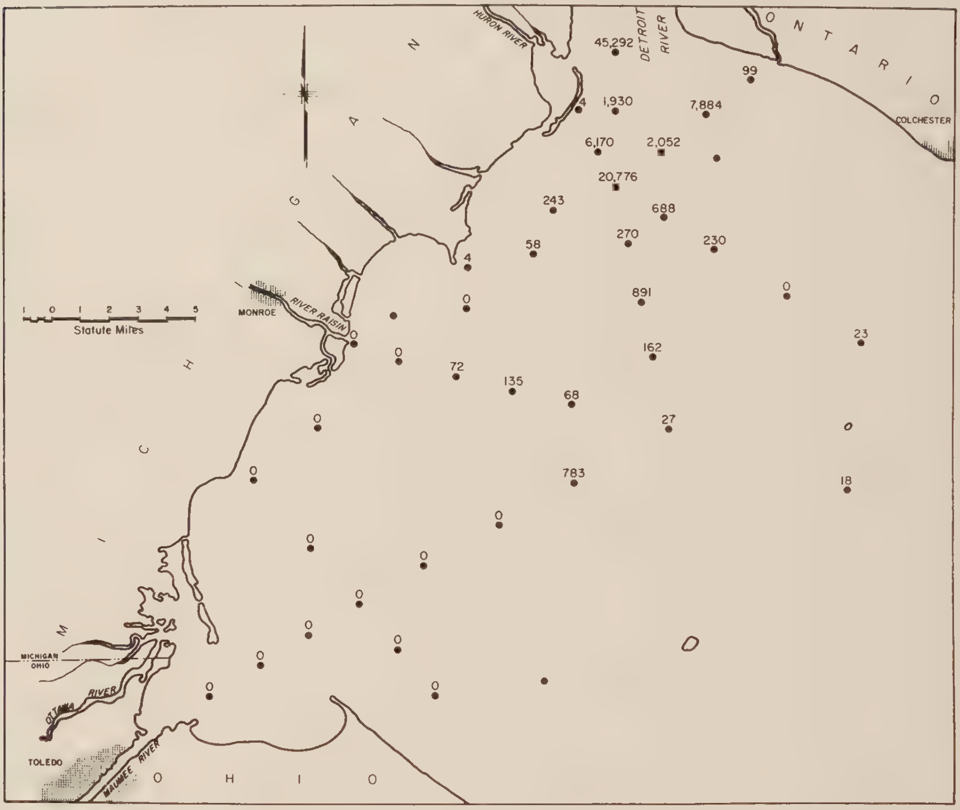
M I C H I G A N
HURON RIVER
DETROIT RIVER
O N T A R I O
COLCHESTER
45,292
99
4
1,930
7,884
6,170
2,052
20,776
243
688
270
230
58
4
0
891
0
MONROE
RIVER RAISIN
0
0
72
135
68
162
23
1 0 1 2 3 4 5
Statute Miles
0
27
0
0
783
18
0
0
0
0
0
0
0
MICHIGAN
OHIO
0
0
0
OTTAWA
RIVER
TOLEDO
MAUMEE RIVER
O H I O

FIGURE 1. Station location and number of Polychaeta per square meter in western Lake Erie. Each sampling station is indicated by a dot. Three samples were taken at each station with a Petersen dredge; screened samples were examined with magnification of 15×. The number above each dot shows the average number of polychaetes per square meter. The figures for three stations are omitted due to unreliable treatment of the samples from those stations.

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## LITERATURE CITED

**Hartman, Olga.** 1951. Fabricinae (Feather-duster polychaetous annelids) in the Pacific. Pacific Sci. 5: 379–391.

**Krecker, F. H.** 1939. Polychaete annelid worms in the Great Lakes. Science 89(2303): 153.

**Leidy, J.** 1858. Proc. Acad. Nat. Sci. Phil. 10: 90.

**Meehean, O. L.** 1929. *Manayunkia speciosa* (Leidy) in the Duluth harbor. Science 70(1820): 479–480.

**Pettibone, Marian H.** 1953. Fresh-water polychaetous annelid, *Manayunkia speciosa* Leidy, from Lake Erie. Biol. Bull. 105(1): 149–153.

**Reisch, D. J.** 1960. The use of marine invertebrates as indicators of water quality. p. 92–103. *In* Erman A. Pearson [ed.] Proceedings of the First International Conference of Waste Disposal in the Marine Environment, University of California, Berkeley. Pergamon Press, New York.

**Wright, S.** 1955. Limnological survey of western Lake Erie, U.S. Fish and Wildlife Serv., Spec. Sci. Rep.—Fish. 139, 341 p.

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*December* 11, 1965)

# Electrophoretic Mobility of an Immune Globulin from Rainbow Trout Serum

Considerable interest has been focused recently on the comparative aspects of the immune response in vertebrates. A sound knowledge of the development of the immune response at various phylogenetic stages in existing vertebrates may clarify the evolution of the various aspects of vertebrate immunity through its highest development in mammals and birds, and provide a better understanding of the mechanisms involved. This communication reports findings concerning the immunoelectrophoretic mobility of an immunologically active fraction of serum from a teleost fish, rainbow trout (*Salmo gairdneri*).

Rainbow trout were immunized by injecting washed rabbit erythrocyte suspensions intracoelomically into a number of fish maintained at a constant water temperature of 15° C. The antisera of highest titre from two of these fish were selected for preparing anti-trout immune globulin sera. Both of these trout anti-rabbit erythrocyte sera were obtained from bleedings made more than 2 months after initial stimulation. The anti-trout immune globulin sera were prepared by injecting three rabbits intraperitoneally three times a week for 2 weeks with saline suspensions of rabbit erythrocytes coated with trout globulin. The rabbit erythrocytes were sensitized by incubation in 1:10 saline dilutions of the trout anti-rabbit erythrocyte sera followed by three washings in 10 volumes of 1 per cent saline solution. One-ml. aliquots of freshly prepared 25 per cent suspensions of sensitized rabbit erythrocytes in saline were used as inocula.

Two other antisera were used in this study. One, a rabbit anti-human serum reagent furnished by Dr. R. S. Weiser, was used to compare electrophoretic migrations of rainbow trout and human serum components. The other, prepared in rabbits from injections of sockeye salmon (*Oncorhynchus nerka*) red cell haemolysate preparations, was used for comparison of electrophoretic mobilities and immunological specificities with salmon globulins previously studied by immunoelectrophoresis[1].

The anti-trout immune globulin reagents were initially screened by the double-diffusion precipitation technique of Ouchterlony as modified by Ridgway *et al.*[2] and were found to contain precipitins. That these were immune and not normal precipitins was confirmed by similar tests comparing pre-immunization sera with post-immunization sera. Immunoelectrophoretic tests were made as described by Krauel and Ridgway[1].

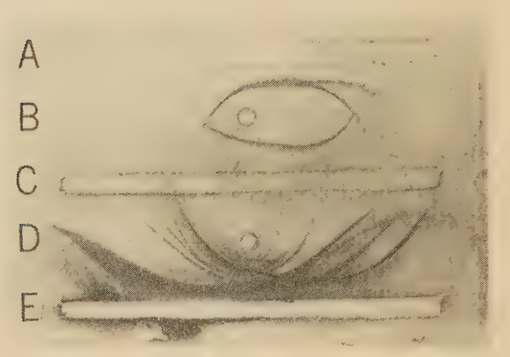

Fig. 1. Immunoelectrophoretic mobilities of globulin components of normal rainbow trout serum compared with components of human serum. *A*, Rabbit anti-sockeye salmon red cell haemolysate antiserum; *B*, normal rainbow trout serum; *C*, rabbit anti-trout immune globulin antiserum; *D*, human serum; *E*, rabbit anti-human serum antiserum

Fig. 1 represents an immunoelectrophoretic slide comparing components in normal rainbow trout serum detected by the anti-trout immune globulin and anti-sockeye salmon haemolysate reagents with components of human serum detected with antihuman serum. When antisera from the other two rabbits were tested against normal trout serum, results were obtained comparable with those of the anti-trout immune globulin reagent used in Fig. 1. These arcs are asymmetrical, indicating that trout immune globulin is heterogeneous with respect to electrophoretic mobility and possibly to molecular size. The anti-haemolysate reagent detected two components in rainbow trout serum of distinct electrophoretic mobilities, the faster component having the same mobility as the component detected by the anti-trout immune globulin reagent. It is of interest to observe in the latter case that, while the mobilities are identical, the two components are not immunologically cross-reactive. Using the human serum–anti-human serum lines as a standard, the two faster components of the rainbow trout serum migrate as beta globulins while the slower component detected by the anti-haemolysate reagent has the mobility of a fast gamma or slow beta globulin.

Neither the beta nor the gamma globulin components of the rainbow trout serum which were detected by the anti-haemolysate reagent have been associated with immunological activity. These components have not been found in all sockeye salmon sera[1], while the component detected by the anti-trout immune globulin reagent has been present in sera of all trout or salmon tested.

Fairley and Harris[3] incubated rabbit erythrocytes in human sera containing normal agglutinins for rabbit red cells. They subsequently found that these sensitized red cells were agglutinated by antisera against complement as well as by antisera against human antibody. In our studies with anti-trout immune globulin sera, the possibility cannot be excluded that the precipitin arc may represent trout complement–rabbit antibody precipitation as well as trout antibody-rabbit antibody precipitation.

No immunologically active globulin with true gamma 2 mobility was detected by this procedure. This accords with the finding of little or no gamma 2 globulin reported by Deutsch and McShan[4] and Engle *et al.*[5] for several species of teleosts; by Clem and Sigel[6] for the margate (*Haemulon albium*); and by Post[7], who partially purified rainbow trout anti-bacterial antibody and studied its mobility by paper electrophoresis. However, Uhr *et al.*[8] have reported significant levels of gamma 2 globulin in anti-phage sera from the goldfish (*Carasius auratus*) 2–4 weeks after immunization, and much increased levels of gamma 2 globulin two months after immunization. Also, Papermaster *et al.*[9] found 'multiple gamma bands' by starch-gel electrophoresis and immunoelectrophoresis in the teleosts they studied. The variations in globulin mobilities reported suggest that either the various experimental approaches result in different responses, or that different species of teleost fish cannot be considered to be identical with respect to the molecular species of globulins with antibody activity.

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[1] Krauel, K. K., and Ridgway, G. J., *Intern. Arch. Allergy*, **23**, 246 (1963).

[2] Ridgway, G. J., Klontz, G. W., and Matsumoto, C., *Bull. 8 Intern. North Pac. Fish Comm.*, 1962.

[3] Fairley, G. H., and Harris, G., *Vox Sang.*, **7**, 175 (1962).

[4] Deutsch, H. F., and McShan, W. H., *J. Biol. Chem.*, **180**, 219 (1949).

[5] Engle, jun., R. L., Woods, K. R., Paulsen, E. E., and Pert, J. H., *Proc. Soc. Exp. Biol. and Med.*, **98**, 905 (1958).

[6] Clem, L. W., and Sigel, M. M., *Fed. Proc.*, **22**, 1138 (1963).

[7] Post, G., *Departmental Information Bulletin*, **63–7**, 42 (State of Utah, Department of Fish and Game, 1963).

[8] Uhr, J. W., Finkelstein, M. S., and Franklin, E., *Proc. Soc. Exp. Biol. and Med.*, **111**, 13 (1962).

[9] Papermaster, B. W., Condie, R. M., Finstad, J., and Good, R. A., *J. Exp. Med.*, **119**, 105 (1964).

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# THE DISTRIBUTION AND ABUNDANCE OF PLANKTONIC DIATOMS IN LAKE SUPERIOR

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*Abstract.* The principal diatoms collected at 14 stations in Lake Superior were *Cyclotella "glomerata-stelligera"* [= *C. glomerata* and *C. stelligera* combined], *Cyclotella "ocellata-kutzingiana," Fragilaria crotonensis*, and *Rhizosolenia eriensis*. Concentrations were heaviest in the Apostle Islands region (up to 2,160 per ml) and lightest northwest of the Keweenaw Penisula (68 to 78 per ml). Species composition differed in different parts of the lake.

## INTRODUCTION

Studies of the plankton of Lake Superior have been limited to shoreward areas, and few have included the identification of phytoplankton. Taylor (1935) described net phytoplankton taken near Isle Royale, and Eddy (1943) listed a few phytoplankters (but no diatoms) in collections from State of Minnesota waters. Putnam and Olson (1961) studied phytoplankton at three stations along the northern shore of western Lake Superior during 1960 and 1961. The U.S. Public Health Service has examined plankton from water intakes near Duluth, Minnesota, and Sault Ste. Marie, Michigan, since 1960, in connection with the national water-quality network (Williams 1963). The present paper is based principally on collections from offshore waters in 1964 and is restricted to the diatoms, which comprise most of the phytoplankton in Lake Superior.

TABLE 1. Locations of stations in Lake Superior at which diatoms were collected in 1964.

| Station number | Latitude (north) | Longitude (west) |
|---|---|---|
| 1 | 46°46'15" | 90°49'50" |
| 2 | 46°54'10" | 90°35'00" |
| 3 | 47°07'00" | 90°52'50" |
| 4 | 47°26'00" | 89°52'00" |
| 5 | 46°58'30" | 89°46'40" |
| 6 | 47°37'00" | 88°37'00" |
| 7 | 47°14'00" | 87°53'00" |
| 8 | 46°58'00" | 88°19'10" |
| 9 | 46°59'00" | 87°41'00" |
| 10 | 46°47'00" | 87°23'30" |
| 11 | 47°11'00" | 87°13'45" |
| 12 | 46°47'10" | 86°55'40" |
| 13 | 46°46'30" | 86°08'00" |
| 14 | 46°49'00" | 84°53'00" |

## METHODS AND MATERIALS

Samples were collected during regularly scheduled cruises of the research vessels *Siscowet* and *Kaho* on Lake Superior, June through November 1964. Two gallons of water were taken by pump or bucket at 14 stations (Table 1, Fig. 1). The samples were treated with the iodine-potassium iodide-sodium acetate preservative described by Utermöhl (1958). The first samples were passed through membrane filters, which were then dissolved in acetone to release the diatoms for cleaning with a concentrated nitric acid-potassium dichromate solution. Later samples were allowed to settle until most of the overlying liquid could be withdrawn and the settled plankton cleaned. The cleaned diatoms were washed until the dichromate color was gone, diluted to 10, 25, or 50 ml in volumetric flasks, and agitated until they were evenly dispersed. One-half ml of the sample was withdrawn

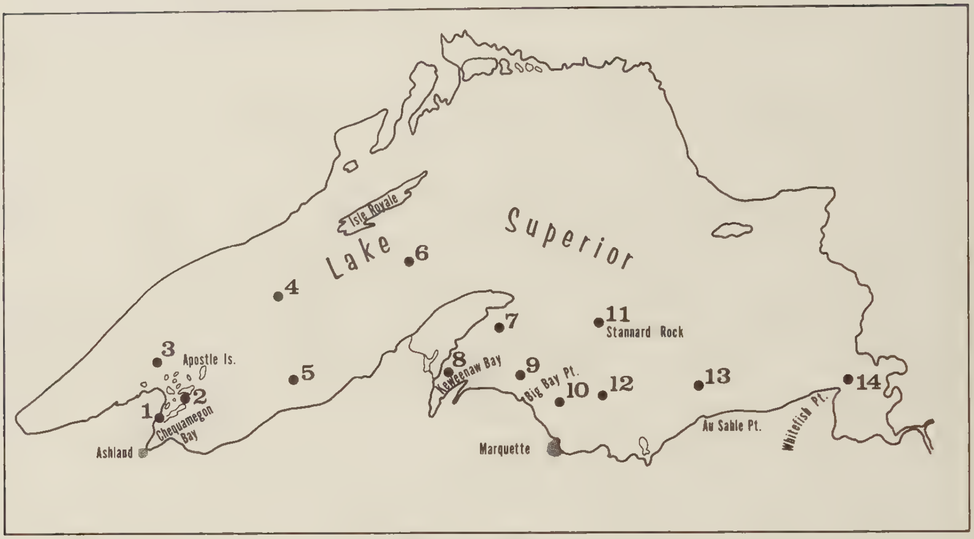

FIG. 1. Locations of stations at which diatoms were collected in Lake Superior in 1964.

by volumetric pipette and dropped onto a coverslip (18 mm square, No. 0). The coverslip was dried on a level hot plate at low heat about 2 hours to effect an even dispersion of diatoms. The coverslip was then heated at 200°C for 1/2 hour to remove residual water from the diatoms, and inverted onto a drop of Hyrax mounting medium on a slide. The slide was heated to 200°C on a hot plate until the bubbling of the Hyrax decreased. As the slide cooled, the layer of Hyrax was made uniform by gentle pressure on the coverslip with a teasing needle.

Diatoms were examined at a magnification of 970 X. Each valve was counted as one-half diatom; broken valves were not included. The diatoms were counted in a strip $193\mu$ wide, across the width of the coverslip. If less than 250 frustules occurred in a strip, counting was continued in another complete strip. The total number of diatoms was calculated from the ratio of the area of the strips which had been examined to the total area of the coverslip (a correction was made by subtracting the area of the corners, where the concentration of diatoms had been reduced during drying). A cursory examination was made of uncleaned material to note the nature of colonial formations and to determine the frequency of occurrence of diatoms that did not contain chloroplasts.

Certain species with overlapping taxonomic characteristics, e.g., *Cyclotella glomerata* and *C. stelligera* in valve view, are reported as combined species—in this case, *C. "glomerata-stelligera."* All hyphenated species names given here represent such combinations. One unidentified species which occurred frequently was designated as *Stephanodiscus* sp. 1. This diatom resembles *Stephanodiscus tenuis* Hust., but is smaller and has more striae per $10\mu$.

## SPECIES OF DIATOMS OF LAKE SUPERIOR

The following diatoms were identified in the collections (asterisks indicate tentative identifications):

_Achnanthes biasolettiana_ Kütz.
_Achnanthes calar_ Cleve
_Achnanthes clevei_ Grun.
_Achnanthes gracillima_ Hust.
*_Achnanthes hauckiana_ Grun.
_Achnanthes lanceolata_ Bréb.
_Achnanthes minutissima_ Kütz.
_Amphora ovalis_ Kütz.
_Amphora perpusilla_ Grun.
_Anomoeneis exilis_ Kütz.
_Asterionella formosa_ Hassall
_Asterionella gracillima_ (Hantzsch) Heiberg
_Ceratoneis arcus_ Kütz.
*_Cocconeis diminuta_ Pant.
_Cocconeis pediculus_ Ehr.
_Cocconeis placentula_ Ehr.
_Cocconeis thumensis_ A. Mayer
_Cyclotella bodanica-comta_ Eulenst.—(Ehr.) Kütz.
_Cyclotella comensis_ Grun.
_Cyclotella glomerata-stelligera_ Bachmann—Cl. and Grun.
_Cyclotella meneghiniana_ Kütz.
_Cyclotella michiganiana_ Skvortzow
_Cymatopleura solea_ (Bréb.) W. Smith
_Cymbella cesatii_ (Rabh.) Grun.
_Cymbella delicatula_ Kütz.
_Cymbella microcephala_ Grun.
_Cymbella prostrata_ (Berkeley) Cleve
_Cymbella turgida_ (Gregory) Cleve
_Cymbella ventricosa_ Kütz.
_Denticula frigida_ Kütz.
_Denticula tenuis_ v. _crassula_ Kütz.
_Diatoma elongatum_ Agardh
_Diploneis marginestriata_ Hust.
_Diploneis oculata_ (Bréb.) Cleve
_Diploneis ovalis_ (Hilse) Cleve
_Epithemia_ (girdle view)
_Eucocconeis flexella_ Kütz.
_Eucocconeis lapponica_ Hust.
_Fragilaria capucina_ Desmazieres
_Fragilaria crotonensis_ Kitton
_Fragilaria intermedia_ Grun.
_Fragilaria pinnata_ Ehr.
_Melosira distans_ var. _alpigena_ Grun.
_Melosira granulata_ (Ehr.) Ralfs
_Melosira granulata_ var. _angustissima_ Müll.
_Melosira islandica-ambigua_ O. Müll.—(Grun.) O. Müller
_Navicula anglica_ Ralfs
_Navicula atomus_ (Naeg.) Grun.
_Navicula cincta_ Cleve
*_Navicula citrus_ Krasske
_Navicula cryptocephala_ var. _veneta_ (Kütz.) Grun.
_Navicula exigua_ Gregory
_Navicula jarnefeltii_ Hust.
_Navicula lacustris_ Gregory
_Navicula laterostrata_ Hust.
_Navicula longirostris_ Hust.
_Navicula minima_ Grun.
*_Navicula muralis_ Grun.
_Navicula pupula_ Kütz.
_Navicula radiosa_ Kütz.
*_Navicula salinarum_ var. _intermedia_ (Grun.) Cleve
_Navicula subhamulata_ Grun.
*_Navicula verecunda_ Hust.
_Nitzschia acicularis_ W. Smith
_Nitzschia dissipata_ (Kütz.) Grun.
*_Nitzschia fonticola_ Grun.
_Nitzschia palea_ (Kütz.) W. Smith
*_Nitzschia sublinearis_ Hust.
_Opephora martyi_ Héribaud
_Rhizosolenia eriensis_ H. L. Smith
_Rhizosolenia longiseta_ Zach.
_Stephanodiscus astraea_ (Ehr.) Grun.
_Stephanodiscus astraea_ var. _minutula_ (Kütz.) Grun.
_Stephanodiscus niagare_ Ehr.
*_Stephanodiscus hantzschii_ Grun.
_Surirella ovata_ Kütz.
_Synedra actinastroides_ Lemm.
_Synedra acus_ Kütz.
*_Synedra amphicephala_ Kütz.
_Synedra cyclopum_ Brutschi
_Synedra nana_ Meister
_Synedra rumpens_ Kütz.
_Synedra tenera_ W. Smith
_Synedra ulna_ (Nitzsch.) Ehr.
_Synedra vaucheriae_ Kütz.
_Tabellaria flocculosa_ (Roth) Knudson

A number of other species of the following genera were distinguished but not identified: _Achnanthes_, 7 species; _Cocconeis_, 3; _Cyclotella_, 1; _Fragilaria_, 1; _Gomphonema_, 2; _Navicula_, 9; _Nitzschia_, 6; and _Stephanodiscus_ 1.

TABLE 2. Frequency of occurrence of common species that contributed less than 5% of the total diatoms in samples from Lake Superior in 1964.

| Species | Percentage occurrence in total samples |
|---|---|
| *Stephanodiscus astraea* var. *minutula* | 75 |
| *Cyclotella michiganiana* | 62 |
| *Stephanodiscus astraea* | 54 |
| *Synedra cyclopum* | 38 |
| *Synedra ulna* | 33 |
| *Nitzschia acicularis* | 33 |
| *Navicula radiosa* | 29 |
| *Melosira granulata* var. *angustissima* | 29 |

The principal diatoms found in this study, in order of decreasing abundance, were *Cyclotella glomerata-stelligera*, *Cyclotella ocellata-kutzingiana*, *Fragilaria crotonensis*, *Rhizosolenia eriensis*, *Asterionella formosa*, *Synedra nana*, and *Stephanodiscus* sp. 1. *Diatoma elongatum*, *Fragilaria capucina*, *Melosira islandica-ambigua*, *Tabellaria flocculosa*, *Achnanthes minutissima*, and *Cyclotella bodanica-comta* were major species at some stations, but not in the lake as a whole (major species are those which made up 5 percent or more of the diatoms in one sample). Species which never made up as much as 5 percent of the total diatoms, but which occurred repeatedly in the collections are listed in Table 2.

## SPECIES COMPOSITION IN DIFFERENT AREAS

Species distribution demonstrates six areas of dissimilar diatom flora for the time period sampled: inner Apostle Islands (Fig. 1, station 1); outer Apostle Islands (stations 2 and 3); the open lake northwest of the Keweenaw Peninsula (stations 4 and 6); the waters southwest and east of the Keweenaw Peninsula (stations 5, 7, 9, 10, 11, 12, and 13); Keweenaw Bay (station 8); and Whitefish Bay (station 14). Among these, populations were most distinctive in the inner Apostle Islands area and the waters southwest and east of the Keweenaw Peninsula.

The density of diatoms was highest (as many as 2,160 per ml) in the inner Apostle Islands. *Diatoma elongatum* was abundant in June, and high numbers of *Achnanthes minutissima* were present in September. It was the only area where *Fragilaria capucina* and *Melosira islandica-ambigua* contributed 5 percent or more of the total diatoms (Table 3).

The area southwest and east of the Keweenaw Peninsula differed from the other areas in that the same three species, *Cyclotella glomerata-stelligera*, *Cyclotella ocellata-kutzingiana*, and *Rhizosolenia eriensis* comprised 75 to 95 percent of all diatoms in August. Although the relative positions of *Cyclotella ocellata-kutzingiana* and *Cyclotella glomerata-stelligera* were reversed in November, the same three species predominated to make up 67 to 78 percent of all diatoms (Table 3).

The stations in Keweenaw Bay and Whitefish Bay were near their mouths and might be expected to reflect conditions in the bay at some times and in the open lake at others. The diatoms at the mouth of Whitefish Bay in August probably reflected bay conditions. *Cyclotella bodanica-comta* was more abundant than at any other station, and *Asterionella formosa* was more abundant than at any other location east of the Keweenaw Peninsula (Fig. 2, Table 3). At the mouth of Keweenaw Bay, *Achnanthes minutissima* was present in great numbers in August, although it was not abundant in adjoining waters outside the bay (Fig. 2); in November the diatom flora was similar to that outside the bay.

TABLE 3. Density of principal species of diatoms in collections from Lake Superior, 1964.

| Station number | Date (1964) | Depth[1] (meters) | Total number/ml (all species) | Principal diatoms[2] | | |
|---|---|---|---|---|---|---|
| | | | | Species | Number/ml | Percentage of total |
| 1 | June 9 | S | 2,160 | *Diatoma elongatum* | 624 | 29 |
| | | | | *Cyclotella glomerata-stelligera* | 499 | 23 |
| | | | | *Fragilaria crotonensis* | 260 | 12 |
| | | | | *Fragilaria capucina* | 149 | 7 |
| | | | | *Melosira islandica-ambigua* | 140 | 6 |
| | | | | *Rhizosolenia eriensis* | 113 | 5 |
| 1 | July 9 | S | 402 | *Tabellaria flocculosa* | 100 | 25 |
| | | | | *Fragilaria crotonensis* | 99 | 25 |
| | | | | *Diatoma elongatum* | 71 | 18 |
| | | | | *Cyclotella glomerata-stelligera* | 29 | 7 |
| | | | | *Cyclotella ocellata-kutzingiana* | 20 | 5 |
| 1 | Sept. 21 | S | 1,585 | *Achnanthes minutissima* | 1,298 | 82 |
| 2 | June 8 | S | 349 | *Fragilaria crotonensis* | 98 | 28 |
| | | | | *Rhizosolenia eriensis* | 83 | 24 |
| | | | | *Cyclotella ocellata-kutzingiana* | 58 | 17 |
| | | | | *Cyclotella glomerata-stelligera* | 38 | 11 |
| | | | | *Stephanodiscus* sp. 1 | 19 | 5 |
| 2 | July 7 | S | 143 | *Cyclotella glomerata-stelligera* | 31 | 22 |
| | | | | *Fragilaria crotonensis* | 31 | 22 |
| | | | | *Cyclotella ocellata-kutzingiana* | 25 | 18 |
| | | | | *Rhizosolenia eriensis* | 16 | 11 |
| | | | | *Synedra nana* | 11 | 8 |
| | | | | *Asterionella formosa* | 8 | 6 |
| 2 | Sept. 22 | S | 120 | *Asterionella formosa* | 32 | 27 |
| | | | | *Cyclotella ocellata-kutzingiana* | 24 | 20 |
| | | | | *Cyclotella glomerata-stelligera* | 24 | 20 |
| | | | | *Fragilaria crotonensis* | 15 | 13 |
| | | | | *Tabellaria flocculosa* | 11 | 9 |
| | | | | *Cyclotella bodanica-comta* | 6 | 5 |
| 3 | June 11 | S | 100 | *Fragilaria crotonensis* | 50 | 50 |
| | | | | *Rhizosolenia eriensis* | 14 | 14 |
| | | | | *Cyclotella ocellata-kutzingiana* | 11 | 11 |
| | | | | *Cyclotella glomerata-stelligera* | 9 | 9 |
| | | | | *Stephanodiscus* sp. 1 | 5 | 5 |
| 3 | July 8 | S | 214 | *Fragilaria crotonensis* | 57 | 27 |
| | | | | *Synedra nana* | 43 | 20 |
| | | | | *Asterionella formosa* | 29 | 14 |
| | | | | *Cyclotella ocellata-kutzingiana* | 25 | 12 |

TABLE 3. Continued

| Station number | Date (1964) | Depth[1] (meters) | Total number/ml (all species) | Principal diatoms[2] | | |
|---|---|---|---|---|---|---|
| | | | | Species | Number/ml | Percentage of total |
| | | | | *Cyclotella glomerata-stelligera* | 19 | 9 |
| | | | | *Rhizosolenia eriensis* | 15 | 7 |
| 3 | Sept. 16 | S | 455 | *Cyclotella ocellata-kutzingiana* | 157 | 35 |
| | | | | *Cyclotella glomerata-stelligera* | 133 | 29 |
| | | | | *Fragilaria crotonensis* | 80 | 18 |
| | | | | *Asterionella formosa* | 39 | 9 |
| 4 | July 28 | S | 78 | *Synedra nana* | 18 | 24 |
| | | | | *Cyclotella ocellata-kutzingiana* | 12 | 15 |
| | | | | *Cyclotella glomerata-stelligera* | 8 | 10 |
| | | | | *Fragilaria crotonensis* | 9 | 11 |
| | | | | *Rhizosolenia eriensis* | 7 | 8 |
| | | | | *Asterionella formosa* | 6 | 7 |
| | | | | *Stephanodiscus* sp. 1 | 5 | 6 |
| 5 | Aug. 18 | S | 296 | *Cyclotella glomerata-stelligera* | 111 | 37 |
| | | | | *Cyclotella ocellata-kutzingiana* | 106 | 36 |
| | | | | *Rhizosolenia eriensis* | 43 | 15 |
| 6 | Aug. 2 | S | 68 | *Fragilaria crotonensis* | 12 | 17 |
| | | | | *Synedra nana* | 11 | 16 |
| | | | | *Cyclotella ocellata-kutzingiana* | 10 | 15 |
| | | | | *Stephanodiscus* sp. 1 | 8 | 11 |
| | | | | *Cyclotella glomerata-stelligera* | 7 | 11 |
| | | | | *Rhizosolenia eriensis* | 7 | 11 |
| | | | | *Asterionella formosa* | 7 | 10 |
| 7 | Nov. 16 | S | 125 | *Cyclotella ocellata-kutzingiana* | 51 | 41 |
| | | | | *Cyclotella glomerata-stelligera* | 28 | 23 |
| | | | | *Rhizosolenia eriensis* | 15 | 12 |
| | | | | *Fragilaria crotonensis* | 9 | 8 |
| 8 | Aug. 11 | S | 504 | *Achnanthes minutissima* | 254 | 50 |
| | | | | *Cyclotella glomerata-stelligera* | 163 | 32 |
| | | | | *Cyclotella ocellata-kutzingiana* | 62 | 12 |
| 8 | Nov. 10 | S | 161 | *Cyclotella ocellata-kutzingiana* | 54 | 33 |
| | | | | *Cyclotella glomerata-stelligera* | 32 | 20 |
| | | | | *Rhizosolenia eriensis* | 22 | 14 |
| | | | | *Fragilaria crotonensis* | 12 | 7 |

TABLE 3. Continued

| Station number | Date (1964) | Depth[1] (meters) | Total number/ml (all species) | Principal diatoms [2] | | |
|---|---|---|---|---|---|---|
| | | | | Species | Number/ml | Percentage of total |
| 9 | Aug. 13 | S | 279 | *Cyclotella glomerata-stelligera* | 102 | 37 |
| | | | | *Cyclotella ocellata-kutzingiana* | 77 | 28 |
| | | | | *Rhizosolenia eriensis* | 59 | 21 |
| | | | | *Fragilaria crotonensis* | 20 | 7 |
| 9 | Nov. 20 | S | 169 | *Cyclotella ocellata-kutzingiana* | 66 | 39 |
| | | | | *Cyclotella glomerata-stelligera* | 39 | 23 |
| | | | | *Rhizosolenia eriensis* | 19 | 11 |
| | | | | *Stephanodiscus* sp. 1 | 16 | 10 |
| | | | | *Fragilaria crotonensis* | 11 | 6 |
| 10 | Nov. 9 | S | 188 | *Cyclotella ocellata-kutzingiana* | 78 | 42 |
| | | | | *Cyclotella glomerata-stelligera* | 43 | 23 |
| | | | | *Rhizosolenia eriensis* | 25 | 13 |
| | | | | *Fragilaria crotonensis* | 15 | 8 |
| | | | | *Stephanodiscus* sp. 1 | 10 | 6 |
| 11 | Aug. 16 | S | 195 | *Cyclotella glomerata-stelligera* | 73 | 37 |
| | | | | *Cyclotella ocellata-kutzingiana* | 65 | 33 |
| | | | | *Rhizosolenia eriensis* | 40 | 20 |
| | | | | *Fragilaria crotonensis* | 10 | 5 |
| 11 | Aug. 16 | 33 | 102 | *Cyclotella glomerata-stelligera* | 30 | 30 |
| | | | | *Cyclotella ocellata-kutzingiana* | 23 | 23 |
| | | | | *Rhizosolenia eriensis* | 22 | 22 |
| | | | | *Fragilaria crotonensis* | 7 | 7 |
| | | | | *Stephanodiscus* sp. 1 | 6 | 6 |
| 12 | Aug. 16 | S | 160 | *Cyclotella glomerata-stelligera* | 44 | 27 |
| | | | | *Rhizosolenia eriensis* | 39 | 24 |
| | | | | *Cyclotella ocellata-kutzingiana* | 38 | 24 |
| | | | | *Fragilaria crotonensis* | 21 | 13 |
| | | | | *Synedra nana* | 11 | 6 |
| 12 | Aug. 16 | 42 | 105 | *Cyclotella glomerata-stelligera* | 32 | 30 |
| | | | | *Cyclotella ocellata-kutzingiana* | 31 | 30 |
| | | | | *Rhizosolenia eriensis* | 20 | 19 |
| | | | | *Fragilaria crotonensis* | 6 | 6 |
| | | | | *Synedra nana* | 6 | 6 |
| 13 | Aug. 17 | S | 226 | *Cyclotella glomerata-stelligera* | 131 | 58 |
| | | | | *Cyclotella ocellata-kutzingiana* | 60 | 27 |

TABLE 3. Continued

| Station number | Date (1964) | Depth[1] (meters) | Total number/ml (all species) | Principal diatoms[2] | | |
|---|---|---|---|---|---|---|
| | | | | Species | Number/ml | Percentage of total |
| | | | | *Rhizosolenia eriensis* | 23 | 10 |
| 14 | Aug. 20 | S | 103 | *Cyclotella glomerata-stelligera* | 37 | 36 |
| | | | | *Cyclotella ocellata-kutzingiana* | 26 | 25 |
| | | | | *Cyclotella bodanica-comta* | 14 | 13 |
| | | | | *Asterionella formosa* | 9 | 9 |

[1] S = surface samples.

[2] Species listed comprised 5 percent or more of the total diatoms in the sample.

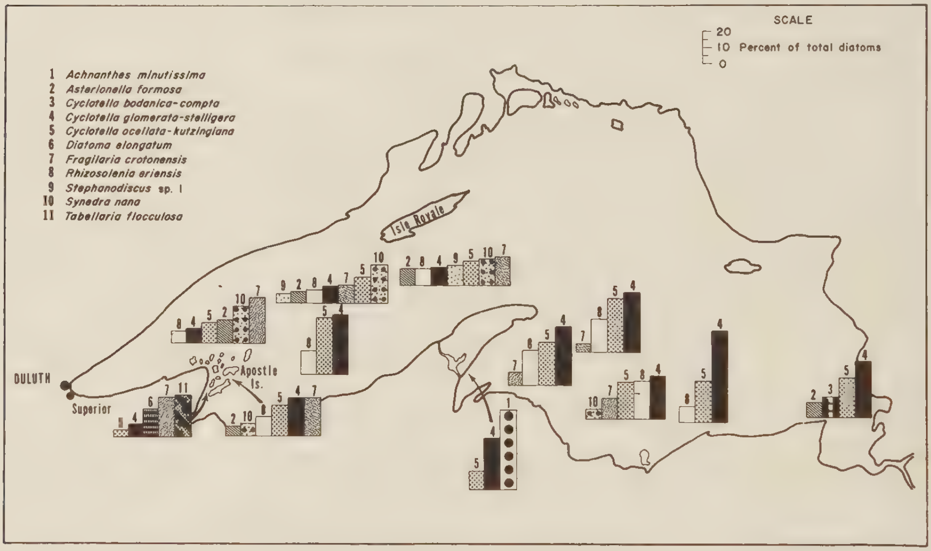
SCALE
20
10 Percent of total diatoms
0
1 Achnanthes minutissima
2 Asterionella formosa
3 Cyclotella bodanica-compta
4 Cyclotella glomerata-stelligera
5 Cyclotella ocellata-kutzingiana
6 Diatoma elongatum
7 Fragilaria crotonensis
8 Rhizosolenia eriensis
9 Stephanodiscus sp. 1
10 Synedra nana
11 Tabellaria flocculosa
Isle Royale
DULUTH
Superior
Apostle Is.

FIG. 2. Relative abundance of major diatom species in surface waters at 12 stations in Lake Superior, July and August 1964 (stations 7 and 10 are not shown).

The collections of July 28 and August 2 in the open lake northwest of the Keweenaw Peninsula and the collections of July 7 and 8 in the outer Apostle Islands area were alike in some respects and different in others. The two areas had the same major species, but the open lake had one additional major species, *Stephanodiscus* sp. 1 (Fig. 2). The open lake had the lowest concentrations of diatoms and the greatest diversity of major species of all areas (Table 3). The outer Apostle Islands area had a greater number of incidental species than the open lake.

Studies of water currents by Rushmeyer and Olson (1958) and by the U.S. Bureau of Commercial Fisheries (Beeton, Johnson, and Smith 1959; and unpublished data) suggested the existence of water masses which might be expected to show ecological variations. These studies suggested a general counterclockwise circulation in the lake and a well-defined littoral current flowing east along the south shore. Evidence exists for an eddy current in Keweenaw Bay and to a lesser extent in Whitefish Bay. The inner Apostle Islands water receives nutrients from the Ashland area. The open lake northwest of the Keweenaw Peninsula probably is a region of weak currents and appears to receive few nutrients from shore. The outer Apostle Islands receive some water from the vicinity of Duluth-Superior, and some from the open lake.

Recognition of limnological differences within the lake limits the extent to which data from one part can be used to characterize the lake as a whole.

## RELATIONSHIP TO OTHER STUDIES

It is difficult to compare this study with others in Lake Superior because of differences in sampling locations and techniques.

Putnam and Olson (1961) counted diatoms in a Sedgwick-Rafter cell at a magnification of 200 X. At this magnification it is very difficult to discern, and impossible to identify to genus, *Cyclotella* in the smaller size ranges into which *Cyclotella glomerata-stelligera* and *Cyclotella ocellata-kutzingiana* fall (lower limit 2$\mu$).

Williams (1963) stated that he counted diatoms 4$\mu$ or larger in a Sedgwick-Rafter cell. He grouped small diatoms into two categories—centrics and pennates—and subdivided the number of these diatoms according to the percentage occurrence of genera and species found on Hyrax slides at a magnification of 900 X. The smaller species of *Cyclotella* would not be detected in the Sedgwick-Rafter count. Consequently, they would not be included in the final count, even though they were detected on the Hyrax slides. The colonial form of some of the small species of *Cyclotella* would further diminish their number, because a natural aggregate occupying up to 300$\mu^2$ would count as one unit. Such an aggregate could be composed of 30 *Cyclotella* frustules, each measuring 5$\mu$ by 2$\mu$.

As compared with the present study, the higher percentages of *Melosira*, *Tabellaria*, and *Asterionella* and the lower percentages of *Cyclotella* found by Putnam and Olson and Williams may have resulted largely from differences in methods.

## TROPHIC IMPLICATIONS

In recent years limnologists have become increasingly concerned about water quality and the role of man in accelerating the eutrophication of lakes. Rather than try to use the occurrence or absence of particular diatom species for classifying lakes on a trophic scale, it might be more meaningful to deal with long-term changes in abundance of species. For example, the two most abundant species in this study were members of the genus *Cyclotella*, which Foged (1954) considered indicative of oligotrophy. The third most abundant species was *Fragilaria crotonensis*, which was considered by Teiling (1955) to indicate eutrophy. Rawson (1956) listed *Fragilaria capucina* as an oligotrophic indicator, but an increase of this species was associated with the eutrophication of Lake Erie (Davis 1964). *Rhizosolenia eriensis*, the fourth most abundant species in Lake Superior, has declined to insignificance in Lake Erie since 1880 (Davis 1964). During the same period of time Lake Erie has undergone accelerated eutrophication (Beeton 1965).

## REFERENCES

BEETON, ALFRED M. 1965. Eutrophication of the St. Lawrence Great Lakes. Limnol. Oceanogr. 10: 240-254.

_________, JAMES H. JOHNSON, and STANFORD H. SMITH. 1959. Lake Superior limnological data 1951-1957. U.S. Fish and Wildlife Serv., Spec. Sci. Rept.—Fish. No. 297, 177 p.

DAVIS, CHARLES C. 1964. Evidence for the eutrophication of Lake Erie from phytoplankton records. Limnol. Oceanogr. 9: 275-283.

EDDY, SAMUEL. 1943. Limnological notes on Lake Superior. Proc. Minn. Acad. Sci. 11: 34-39.

FOGED, N. 1954. On the diatom flora of some Funen lakes. Folia Limnol. Scand. 6: 75 p.

PUTNAM, HUGH D., and THEODORE A. OLSON. 1961. Studies on the productivity and plankton of Lake Superior. School of Public Health, Univ. Minnesota, Litho. 72 p.

RAWSON, D. S. 1956. Algal indicators of trophic lake types. Limnol. Oceanogr. 1: 2-25.

RUSHMEYER, O. R., and T. A. OLSON. 1958. Water movements and temperatures of western Lake Superior. School of Public Health, Univ. Minnesota, Litho. 65 p.

TAYLOR, WILLIAM RANDOLPH. 1935. Phytoplankton of Isle Royale. Trans. Amer. Microsc. Soc., 54: 83-97.

TEILING, E. 1955. Some mesotrophic phytoplankton indicators. Verh. int. Ver. Limnol. 12: 212-215.

UTERMÖHL, HANS. 1958. Improvements in the quantitative methods of phytoplankton study. Verh. int. Ver. Limnol. Communication No. 9, 27 p.

WILLIAMS, LOUIS G. 1963. Plankton population dynamics. U.S. Public Health Serv. Publ. No. 663, 90 p.

# A Standard Terminology and Notation for Otolith Readers

BY ALBERT C. JENSEN[1]

## Abstract

One- and two-word terms are used to describe features and markings seen in otoliths. The terms are accompanied by synonyms and full definitions. Abbreviations and number notations describe certain characteristics (including clarity of markings) of otoliths.

## Introduction

Results of the cod otolith exchange program (Anon., 1959), and the analysis of a questionnaire (Keir, 1960) distributed to biologists engaged in age determination of fishes, indicated some important disagreements between different workers, particularly in the terminology used to report their findings. Because of the fundamental importance of age data to the work of the International Commission for the Northwest Atlantic Fisheries (ICNAF), the Standing Committee on Research and Statistics recommended at the 1960 Annual Meeting (Anon., 1960) that a working party on ageing techniques be set up to resolve these disagreements and to draw up a uniform set of terms and symbols.

Dr Gunnar Rollefsen was appointed Convener of the working party that met in Bergen, 19–24 November 1962. During the meeting the working party discussed a preliminary listing of terms, definitions, and abbreviations prepared by the author. The present paper represents the consensus of the members of the working party and was adopted by the Standing Committee on Research and Statistics of ICNAF for gadoids, redfish, and halibut at its Annual Meeting for 1964. The paper is prepared for use in the laboratories of ICNAF members, in otolith exchange reports, and in the preparation of papers dealing with otolith studies.

## Terminology

The terms have been kept as simple as possible (Table 1). Preference has been given to terms that have precedence in the literature or have a valid historical basis. Quite often the oldest term is the best term.

Terms that deal with validity of methods (e.g., year-marks), and terms for which the dictionary definition has been replaced by a common usage definition (e.g., annulus) are not considered here. The proposed terms are intended to be descriptive and of a restricted nature. Also, they are terms that will have a similar meaning when translated from English, the official language of ICNAF, into the various languages of the ICNAF members.

## Notation

### Character of otolith zones

A system of number notations is proposed to grade the character (readability) of the otolith zones (Table 2). Such notations can also serve as a guide to the reliability of the ages determined for each otolith. The numbers will permit use of these notations in IBM and similar machine systems.

### Abbreviations and symbols

It is desirable to keep abbreviations and symbols to a minimum and as simple as possible. Any lengthy comments on the appearance of the otolith and its markings, or on the degree of confidence of the determined age, are best made in an appropriate remarks column on the form used to record the results of the otolith readings.

Asterisks, plus and minus signs, or other addenda to the age notation, serve only to clutter the data. When comparing the results of duplicate otolith readings, the reader's first concern is, "Do the ages agree?" After this, the question may be asked, "Why did the duplicate readings agree (or disagree)?" Symbols and remarks will serve to answer the second question, but they should not clutter the sheet such that, after the otolith has been studied and an age assigned, the data sheet must be studied to find the notation of age.

### Type of edge growth

Determining the type of growth (hyaline or opaque) seen at the edge of the otolith can, at

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TABLE 1. Terminology to describe otolith marks.

| Term | Synonyms | Definition |
|---|---|---|
| Zones | Annuli, rings, year marks, bands, winter rings, summer rings, growth zones | Bands of concentric hyaline or opaque material seen in otolith and counted for age determination. |
| Check | Check mark, check ring, false ring, secondary ring, secondary zone, split | Hyaline matter not counted in age determination. Checks are sometimes indistinct, discontinuous, or, in the judgment of the reader, do not meet the criteria established for identification as a year mark. |
| Nucleus | Focus, center, origin, kernel | The central area of the otolith bounded by the first check or zone. (In most laboratories the center of the otolith is not fully understood, thus many biologists have not yet developed a firm definition for this term.) |
| Opaque edge | Summer edge, fast-growth edge, dense edge | The otolith periphery composed primarily of white, material that blocks light. |
| Hyaline edge | Winter edge, slow-growth edge, transluscent edge | The otolith periphery composed primarily of translucent material that passes light. |
| Spawning zones | Spawning marks. spawning rings | Hyaline and opaque zones formed in the otolith from the onset of sexual maturity. (For gadoids, both hyaline and opaque zones of spawners are, in general, uniform in size and form, and the opaque zones are distinctively narrower than those formed during the immature period of the fish's life. The hyaline spawning zones are clear and usually free of opaque material; in many species (e.g., cod) they are frequently broader than the subsequent opaque zones.) |

TABLE 2. Notation to describe the character of otolith zones.

| Notation and term | Definition |
|---|---|
| O — Good | The zones are plainly visible with generally good definition between hyaline and opaque zones. Any check readily identifiable as such. The reader has a good degree of confidence in resulting age determination. |
| 1 — Fair | The zones are visible but not well defined. There are many checks present. The reader has fair degree of confidence in resulting age determination. In many otoliths the zones may form distinct patterns that make reliable age determinations feasible. |
| 2 — Poor | The zones are vaguely marked. Otoliths with zones so poorly defined as to be undecipherable, or where the age is merely estimated, are placed in this category. |

times, be difficult and sometimes depends upon the subjective judgment of the reader. Final determination of the type of edge growth is influenced by the manner in which the otolith is read (whole, cut, or broken) and often the beginnings of new growth are best seen at the narrow tip of the long axis of the otolith. These factors must be taken into consideration by the reader when he records his observation of the type of edge growth. Since the type of edge growth is used to translate age determinations from zone counts, recognition of the edge type is essential to the otolith reading process. To help him in this recording, the following abbreviations are suggested:

Hn — narrow hyaline zone at edge (1)
Hw — wide hyaline zone at edge (2)
On — narrow opaque zone at edge (3)
Ow — wide opaque zone at edge (4)

For card punch systems (IBM, Keysort, etc.), the numerical notation may be substituted for the abbreviation, but care should be exercised to avoid confusing the edge code number with the age or zone-count number.

**Checks**

$C_{3,4}$ — check in third and fourth opaque zone

**Spawning zones**

12 (4s) — total of 12 zones of type counted (hyaline or opaque), 4 of which are spawning zones

**Age determination**

9 — clearly, nine completed zones of the type counted
9(10) — probably nine, possibly ten completed zones
(8)9(10) — probably nine but possibly eight or ten completed zones
12(?) — best estimate of count from ambiguously marked otolith

### Summary

In 1960, the ICNAF Standing Committee on Research and Statistics recommended that a working party on ageing techniques be convened. A function of the working party was to discuss a uniform set of terms and symbols to be used in reporting the results of otolith studies.

The working party met in Bergen, Norway in the autumn of 1962. A proposed set of terms and notations, presented to the working party, was discussed, revised and accepted.

The terminology includes one- and two-word terms, their synonyms, and full definitions, to describe features and markings seen in otoliths.

Notations to describe characteristics of the otoliths are presented with abbreviations. Numerals are suggested, where feasible, for use in electronic data processing systems.

### Acknowledgements

I wish to thank Dr Birger Rasmussen and the members of the working party for their suggestions and comments, many of which are included here.

### References

ANONYMOUS. 1959. Report of the ad hoc subcommittee on the ICNAF cod otolith exchange program. Report of the Standing Committee on Research and Statistics to the *Annu. Meet. int. Comm. Northw. Atlant. Fish.* 1959, p. 48–50.

1960. Report of subcommittee on ageing techniques. Report of the Standing Committee on Research and Statistics to the *Annu. Meet. int. Comm. Northw. Atlant. Fish.* 1960, p. 37.

KEIR, RONALD S. 1960. Techniques for reading otoliths. *Annu. Meet. int. Comm. Northw. Atlant. Fish.*, 1960. Document No. 4 (mimeographed).

# 38. THE GENERAL DISTRIBUTION OF SPECIES OF THE CALANOID COPEPOD FAMILY CANDACIIDAE IN THE INDIAN OCEAN WITH NEW RECORDS.

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As manifested in the distribution of species of the copepod family Candaciidae, the western Indian Ocean can be divided into three main plankton communities. North of about latitude 20° South, equatorial species predominate. In the extreme western limits, those species are carried southward by the Agulhas Stream.

From latitude 20° South to about 38° South, species characteristic of the southern Central Water are found.

In the Arabian Sea and the Bay of Bengal, neritic or intermediate forms are found. These are apparently associated with the chemical or physical influence of land and the outflow of rivers.

New records include *Candacia samassae* reported for the first time from the Arabian Sea and the Bay of Bengal. This species was originally described from the Red Sea and has not until now been found elsewhere. Another new record is that of *C. guggenheimi* Grice and Jones reported here from the western Indian Ocean and previously known only from the Central Pacific.

Symposium on Crustacea, held under the auspices of the Marine Biological Association of India at the Oceanographic Laboratory, University of Kerala, Ernakulam, 12-15 January, 1965, Abstract of Papers, p. 17-18.

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# 39. EVIDENCE OF ISOLATION BETWEEN POPULATIONS OF *CANDACIA PACHYDACTYLA* (DANA) (COPEPODA: CALANOIDA) IN THE ATLANTIC AND THE INDO-PACIFIC OCEANS

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Atlantic and Indo-Pacific samples of *Candacia pachydactyla*, a calanoid copepod inhabiting equatorial waters, were examined for differences in morphological characteristics. Such differences were found between samples from the two oceans and are believed to be evidence of genetic isolation of two populations.

Distribution data indicated that the Indo-Pacific population is not carried around the tip of Southern Africa into the Atlantic by the Agulhas Stream. About 2000 miles of water appeared to separate the two populations.

Symposium on Crustacea, held under the auspices of the Marine Biological Association of India at the Oceanographic Laboratory, University of Kerala, Ernakulam, 12-15 January, 1965, Abstract of Papers, p. 18.

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